Interfaces with Other Disciplines

Pricing, market coverage and capacity: Can green and brown products co-exist?

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Article Info

Keywords:
OR in marketing
Sustainable operations
Product portfolio
Capacity
Market segmentation

Abstract

Environmental strains are causing consumers to trade up to greener alternatives and many brown products are losing market coverage to premium-priced green rivals. In order to tackle this threat, many companies currently offering only brown products are contemplating the launch of a green product to complement their product portfolio. This paper provides strategic insights into and tactical ramifications of expanding a brown product line with a new green product. Our analysis explicitly incorporates a segmented consumer market where individual consumers may value the same product differently, the economies of scale and the learning effects associated with new green products, and capacity constraints for the current production system. It is shown that a single pricing scheme for the new green product limits a firm's ability to appropriate the value different customers will relinquish in a segmented market and/or to avoid cannibalization. A two-level pricing structure can diminish and even completely avoid the salience of cannibalization. However, when resources are scarce, a firm can never protect its products from the threat of cannibalization by just revising the pricing structure which can spell the end of its brown product's presence in the market or preclude the firm from launching the green product. At this point, the degree of cannibalization is higher for the brown product when the green product offers a sufficiently differentiated proposition to green segment consumers.

1. Introduction

"Green" sits at the head of the boardroom charts for many brown companies nowadays. The reasons are many. Shoppers are suddenly hyperconscious of sustainability-related issues and in response they are changing their shopping lists and skewing their purchases to those products deemed environmentally sound. As of 2009, nearly 85 percent of U.S. consumers purchased a wide range of green products representing such categories as compact-fluorescent lamps, natural household cleaning, energy-efficient electronics and appliances, rechargeable batteries, and organic foods. Propelled by this soaring interest in green shopping, a raft of green brands, such as Seventh Generation and Tom's of Maine that started out as a credible response to the environmental concerns of the most ardent green shoppers, branched out into mass marketers of widely distributed green products. Seventh Generation's sales were $150 million in 2008, up 20 percent over 2008, and their cleaning products are now lined up on the shelves of many mainstream supermarkets in addition to visible storefronts like Target and Whole Foods. Equipped with a better grasp of environmental issues and adept at catering to the needs of today's fast-growing eco-aware consumers, these green brands have taken advantage of opportunities to grow their top-line sales and market coverage – and even evolve their businesses.

Managers of branded brown companies face tough new standards in this more environmentally sensitive business climate. Conventional marketing that entails launching new products with better quality, performance and convenience at affordable prices now needs to integrate a focus on incorporating green issues in the product development process. The success of a raft of green brands such as Patagonia outerwear and Tom's of Maine toothpaste proves that consumers want to see environmental benefits in the products they buy and that brown companies must leap in a sustainable fashion – rather than tweak – to partake of growth opportunities in green marketplace. Moreover, numerous up-and-coming firms with a deep-green orientation and with promising green brands are now assertively nipping at the heels of brown companies, and they are facing continuous losses in share to these aggressive green competitors. Encouraged by the potential of green-oriented sales and propelled by the fear of being edged out by green rivals, more and more well-established...
brown companies now look for ways to green up their products and introduce new exciting brands that are more in sync with nature. Just a few notable examples include Nike Organics clothing (made from 100 percent organic cotton), Philips Alto II fluorescent lamps (having the lowest mercury level of 1.7 milligram per lamp in the industry), Toyota Prius hybrid sedan (with an exceptional fuel efficiency rate gauged at 51 miles per gallon in city and 48 miles per gallon on highway), and Caroma dual-flush toilets (reducing water usage by up to 67 percent compared with traditional toilets).4-6,7

In a headlong rush to attract new green-leaning customers that would pay hefty premiums for green products and/or win back customers that have switched to a green rival, many brown companies are often tempted to offer the greenest of mainstream products. When it works, the combination of a brown and a green brand in the market allows those companies to calibrate those two offerings to their own strategic advantage. On the other hand, once launched, today’s crop of green products have a growing tendency to also steal customers from these companies’ existing portfolio of brands. In the case of green products which embody significantly less environmental impact in addition to all those consumer demands such as price and convenience, this threat can be more and more daunting. Add to this the challenge that no products stand alone. A new green product cannot be simply added into an existing production system in isolation, and creating a new green brand forces a firm with a pre-existing brown brand in his current system to divide his resources rather than concentrate his efforts on the business at hand. Not to mention that a new green brand can end up wreaking havoc with the finances of such companies by siphoning away more funds than do its brown counterparts because it uses new materials or technologies piling up on the inherent costs of the launch, marketing communications, and hiring and training of new staff. In order to surmount all these hurdles to their advantage and convert these two potential enemies into profitable allies, the managers of branded brown companies must understand in depth how green consumers and their green purchasing motivations differ markedly from those of brown consumers, and carefully leverage their system in which brown and green products are envisaged to operate.

These observations motivate the focus of this paper. This paper attempts to enrich the product portfolio management problem faced by a firm operating under a production capacity with a focus on green products and on factors related to the market that is segmented by customers’ commitment to green and green purchasing behavior.8 We identify implications of expanding the product line with a green product by considering the following important characteristics of green products: (1) a green product is typically a high-price alternative to the brown product; (2) green products can have lower valuation or higher valuation from regular/brown consumer segments depending on how the green product is positioned in the market; (3) with their green image, green products provide high value to a relatively small – albeit growing – green consumer segment; (4) a new green product typically ends up being more costly to produce than brown products because they lack economies of scale, or because they use new materials or new technologies; and (5) green product development is subject to a higher level of uncertainty (e.g., technical, market and organizational) that resolves over time as more green products are adopted by consumers due to learning effects. In particular, we attempt to examine the following questions: (1) What are the benefits and hazards associated with expanding product line with a green product? (2) Are the benefits derived from higher market coverage or higher selling price of the green product? (3) What is the impact of a firm’s production capacity on his production line producing a green product and a brown product? (4) Under what conditions does a firm’s investment in additional production capacity to ease the congestion in the product line pay off? and (5) What are the economic implications of cumulative production volume learning effects of a new green product on the value that can be extracted from a segmented consumer market?

The unique contributions of our research are as follows. We show that when introducing a new green product, it is crucial to have a keen grasp of green and brown consumers’ differing coordinates of value, and to use these coordinates in pricing strategies to hit one target segment while deliberately missing the other. The firm should adopt a two-level pricing regime for his green product to fully extract the value from green and brown segment consumers, which in turn can expand the market coverage for the firm. Our analysis also shows that in the current market environment, offering a new green product at a premium price in the pursuit of exploiting green consumers’ willingness-to-pay can preclude the firm from maximizing the overall profits of his product line, even if it results in higher market coverage. On the other hand, offering the green product at a relatively lower premium cannot only maximize profits but also diminish (and even completely avoid) the threat of cannibalization. When resources are limited, the firm can protect his existing brown product from cannibalization only at the expense of his new green product, and this could prevent the firm from launching the green product.

The remainder of this paper is organized as follows. Section 2 positions our research in the context of current work on green product introduction. Section 3 describes the model and states its basic assumptions. In Section 4, we first analyze the profitability conditions of increasing product variety with a green product without capacity considerations, and then incorporate the issue of limited resources and its impact on increased product variety. Finally, Section 5 summarizes the key results and managerial implications of our research.

2. Literature review

Product variety issues have been extensively studied in economics, marketing and operations management literature. The reader is referred to Lancaster (1990), Krishnan and Gupta (2001) and Ramdas (2003) for comprehensive reviews. Management of product variety involves deciding what and how many products to offer, the target consumer market(s), and introduction timing for each product. Creating and offering distinctive products can result in costly changes to manufacturing and other processes. On the other hand, broader specialized product lines can allow higher prices to be charged and may help to increase market coverage by enabling a firm to better satisfy the needs of distinct consumer segments in the marketplace. The implications of product variety on costs and firm performance are described and empirically verified in Kekre and Srinivasan (1990), and in Bayus and Putsis (1999). Marketing research popularizes utility models where products are characterized via quality-type attributes and consumer preferences are elicited over these product attributes. They

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8 The focus on a single firm is driven by several industry examples such as: (a) Toyota making the decision on introducing the Prius as a “green” alternative to their regular automobiles; (b) Cascade introducing an eco-friendly dishwashing liquid to complement his regular products; (c) GE introducing the energy efficient lightbulbs (CFLs) while continuing to market their traditional products; (d) Target introducing an eco-friendly clothing line along with the other regular clothing products; (e) Brooks introducing a biodegradable running shoe to complement his current product offerings; (f) Continental airlines choosing to invest in fuel-efficient airplanes when making decisions for aircraft replacement; (g) Nike launching Nike Organics, a full line of clothing made from 100 percent organic cotton; and (h) Caroma dual-flush toilet that is a pioneer in waste recycling technology with its half-flush and full-flush technology that reduces water usage by up to 67 percent compared with traditional toilets, which use almost 3 gallons per flush. In most (if not all) of these cases, the green product was added to an existing brown product line to primarily serve the needs of an existing market rather than in response to competitive pressures.
emphasize product line design and associated pricing decisions to extract value from a heterogenous consumer population by selecting a product portfolio to maximize profits, revenues or market coverage. In their seminal work, Mussa and Rosen (1978) derive a firm’s optimal price-quality schedule offered to a heterogeneous consumer population with a continuous preference parameter along the quality dimension over a bounded range. Moomth (1984) substantiates the benefits of market segmentation through product line design. Kim and Chhajed (2002) generalize these models by considering multiple attributes, but with a consumer market partitioned into two distinctive segments.

The utility models employed in the above literature enable a firm to estimate how much revenue is gained from a chosen set of products and to determine whether it stems from cannibalization, market expansion or competition. However, they usually overlook the cost implications of product variety and product line choice. To address this shortcoming, Dobson and Kalish (1988) introduce both fixed and variable production and marketing costs associated with each product introduced, and propose a model to solve the problem of how many products to introduce, where to position them and how to price them so as to maximize total profit. Raman and Chhajed (1995) assume manufacturing costs are determined by product attributes along which customers perceive variety and include attribute-level costs for attributes that share production resources to address any potential design synergies across different products in manufacturing. Dobson and Yano (1995) model cost interactions based on the usage of shared or product-specific technological and design resources. Morgan, Daniels, and Kouvelis (2001) examine how product variety decision is affected by a firm’s cost structure, dictated by the relevant manufacturing capabilities and the degree to which a firm designs variety of products that can be offered with minimum impact on manufacturing requirements. Product line characteristics they study include profitability, breadth, diversity of manufacturing requirements associated with selected product mix, and market coverage. Ramdas and Sawhney (2001) argue that while consumers perceive variety at the product level, costs are driven by components. Based on that they evaluate multiple line extensions that simultaneously consider revenue implications of component sharing at the product level and cost implications at the component level. Recently, Heese and Swaminathan (2006) characterize environments where product line design with component commonality yields higher revenues through explicitly considering potential interdependencies between cost reduction efforts and quality decisions. In a similar framework, Krishnan and Zhu (2006) analyze designing a special class of products for which the fixed costs of development far outweigh the unit variable costs. Netessine and Taylor (2007) characterize the impact of production technology on the product variety decisions and product line design with an economic order quantity model. In that work, the number of products affects the extent of the economies of scale, product quality affects inventory holding costs and vice versa, and together they affect setup costs and prices. The main shortcoming of these models is that they fail to capture the full complexity of product demand interactions. This is also highlighted by Kim and Chhajed (2001), stressing that customers’ perceptions about individual products should be a function of the entire set of products offered by a firm.

In all the above literature, there is no explicit consideration of capacity-related costs in installing the needed capacity for an effective service level, and the effects of capacity limitations on the product variety management and product line design are ignored. A firm does not possess unlimited resources for offering a variety of products and often faces capacity constraints in the form of labor, equipment, space or inventory. The limitations on capacity leads to competition between the products of a firm for these resources in addition to consumer demand. In the presence of a production capacity, increased product variety typically increases operational complexity, and actual physical output needed for meeting consumer demand is dependent on what products to offer and how many to produce. The reader is referred to Yano and Dobson (1998) for a review of deterministic product assortment problems that can be formulated as an integer programming problem and that incorporate production capacity, production technology, and product assortment and pricing decisions. In the presence of shared manufacturing capacity, Dobson and Yano (2002) address the issue of determining which of many potential products to offer and how to price them, taking into account sensitivity of consumer demand to both price and delivery response time. Boyaci and Ray (2003) focus on a monopolist firm that sells two substitutable products and that possesses dedicated capacities for each product, and analyze how product differentiation decisions are influenced by capacity costs and how the differentiation strategy of the firm changes in response to a change in its operating dynamics. It is shown that while the degree of product differentiation depends on the absolute and relative values of the capacity costs, the optimal pricing decision is additionally dictated by the market characteristics. Dana and Yahalom (2008) generalize the model proposed in Mussa and Rosen (1978) by introducing an aggregate resource constraint. Recently, Tang and Yin (2010) address this issue by analyzing the impact of a firm’s production capacity on the optimal product line selection, optimal price and optimal production quantity of each selected product. More recently, focusing on a queuing model, Chayet, Kouvelis, and Yu (2011) investigate the factors determining the right level of product variety to offer, the relative positioning of the products in the line, and the resulting effects on production costs and congestion levels of the processes. It is shown that per-unit capacity investment and consumer waiting costs act as deterrents for higher product variety for product-focused processes. For product-flexible processes, optimal product variety also depends on the specific type of flexibility and the ratio of capacity investment to variable production costs.

There is also some relevant research on green product development. Chen (2001) addresses the conflicting nature of product attributes through analyzing the strategic and policy issues of green product development. In a similar framework, Krishnan and Lecourbe (2010) examine the environmental and economic consequences of green product development and identify conditions under which the dual goals of benefiting the environment and higher firm profits can be achieved. Yenipazarli, Bala, and Vakharia (2013) address the market challenges in their stylized model that incorporates consumer preferences for green attributes and positive market externalities, as well as strategy specific supply side effects, to investigate the choices and trade-offs associated with firms’ green product development decisions. Likewise, Yenipazarli and Vakharia (2013) analyze two alternative green product development strategies a firm with an existing brown product can choose and implement for incorporating environmental considerations into his product design. This promising line of research, however, ignores the economic implications of operational elements such as capacity limitations and learning curve effects on a firm’s product variety and product line design decisions.

We contribute to the literature in product variety management in several ways. The novelty of our model and subsequent analysis is driven by the market structure, which is segmented by customers’ commitment to green and purchasing behavior, and from the distinct product valuation functions of customers in these respective segments. It is reported by marketing institutes that observe consumer trends over time that the incidence of green purchasing is so prevalent throughout the U.S. population, and hence customers need to be segmented psycho-ographically in order to zero in on one’s most appropriate target customers. The importance of segmenting customers into distinct and mutually exclusive groups is that it makes targeted marketing of green and brown customers possible. In such a market structure, we factor in the differing valuations (or maximum willingness-to-pay) of customers in distinct market segments for green and brown products. In particular, the asymmetry in the value customers derive from a green product allows us to analyze
different pricing regimes that can be employed by a firm for his brown and green products so that he would be able to extract more surplus from both consumer segments. It is also important to note that in contrast to previous studies that focus on optimal quality and pricing decisions of a firm, we do not characterize brown and green products with respect to their quality levels. The underlying reason is that with the modeling approach of earlier studies, it is almost always difficult, in practice, to identify and quantify (1) the quality level(s) of a product and (2) the marginal willingness-to-pay of each consumer on each of these quality dimensions. More importantly, the heterogeneity in purchasing behavior of customers in each segment cannot be captured because the respective parameters are constant. In our model, we overcome these issues by considering the maximum willingness-to-pay of customers in each segment for brown and green products and by assuming that it is uniformly distributed on a given support.

Another key distinguishing feature of our paper is the incorporation of the key characteristics of green products into our analysis. For starters, industry observations point out that a green product typically ends up being more expensive to produce than a traditional product (due to lack of economies of scale or to the use of new materials and/or new technologies) and so is a premium-priced environmentally preferable substitute for its traditional counterpart. Based on that, we impose in our analysis that green product must be priced higher than the brown product. Second, a higher level of market and organizational uncertainty is attributed to the green product development process which resolves over time as more green products are produced and then adopted by customers. In our model we factor in this well-pronounced observation by explicitly considering the impact of learning effect on the unit production costs of a green product. To the best of our knowledge, our model is the first attempt in new product introduction literature that jointly considers the green products, the learning effect and capacity issues. It is also important to note that our main focus here is on the most efficient use of installed capacity of a firm that is in the pursuit of expanding his product line with a new green product. This approach differentiates our analysis and findings from the previous related studies that typically assume that additional capacity can be procured (if needed) and hence that only offer guidelines to assess the impact of expanding the product line on required capacity. A final issue to touch upon is how we extend the current state of thinking in the green product introduction literature. The related studies in this area primarily focus on the trade-offs between environmental and traditional attributes in product design, the environmental consequences of green product development and specific strategies that can be adopted by firms launching green products. Our perspective instead is to examine whether and under what conditions a firm with limited production capacity would benefit from adding a green product into his existing line.

3. Modeling framework

In this section, we detail our modeling assumptions and formulate the firm’s profit function under different pricing regimes.

3.1. Consumer characteristics

Consumers are heterogenous with respect to their willingness-to-pay \( \theta \), distributed uniformly in the interval \( [0, 1] \), and each consumer buys at most one unit of a product. The market size is normalized to 1. There are two types of consumers – brown (\( B \)) and green (\( G \)) consumers – and the green consumers’ proportion in the market is given by \( \beta \in (0, 1) \). The firm can offer at most two types of products; a brown product (\( b \)) and a green product (\( g \)), with \( p_b \) and \( p_g \) denoting the prices of the two products, respectively. Throughout our analysis we consider cases where the firm prices the new green product higher than the brown product (i.e., \( p_g > p_b \)) as it is the relevant case for practice.

Brown segment and green segment consumers both value the brown product at \( \theta \). The brown consumers derive a value from the green product at \( v/\theta \) with \( v < 1 + (p_g - p_b) \). This would allow us to incorporate two conflicting observations of the market studies on green purchasing. On the one hand, market evidence shows that environmental benefits appeal to only the niche green customers and they are not likely to attract mainstream brown customers unless they also offer a desirable benefit, such as cost-savings. According to these studies, many green products have failed because they are hurt by the perception of brown customers (who buy green products for non-environmental benefits) that these products overemphasize and deliver environmental promises at the expense of the non-green consumer values, such as price, additional features and convenience, brown customers desire.\(^9\) Such lower perception of brown consumers for green products is captured by the values of \( v < 1 \). On the other hand, there is also some market evidence that green products are perceived to be of higher quality than brown products which can be reflected in consumers’ willingness-to-pay higher prices for green products.\(^10\) In such cases where brown customers derive higher values from green products in comparison to brown products, one can consider using the values of \( v \in [1, 1 + (p_g - p_b)] \). Notice that in this scenario the upper-bound on the value of the parameter \( v \) is moderated by the price differential between green and brown products such that the higher the price differential, the greater is the possible maximum value of \( v \).

In contrast to conflicting market evidence on the purchasing behavior of brown consumers, it is consistently reported that green consumers have strong environmental values, take it upon themselves to try to affect positive change in the market, prioritize environmental benefits of a product over non-green values, such as style, size and price, readily pluck green products off the shelf and are very likely to avoid products that are not environmentally conscious when an environmentally friendly substitute is available in the market. Green customers are dedicated to green purchasing and green behaviors (e.g., recycling), and they tend to be less sensitive to price than brown customers, and particularly so for greener products. To be consistent with these observations, we assume that when a green consumer values the brown product at \( \theta \), she values the green product higher at \( \kappa \theta \) where \( \kappa > 1 \). These parametric assumptions on \( v \) and \( \kappa \) lead to two possible product valuation possibilities:

- The valuation of the green product is higher than the valuation of the brown product for customers in the green segment (driven by \( \kappa > 1 \)), and if \( v \in (0, 1) \), then the valuation of the green product is lower than the valuation of the brown product for customers in the brown segment; and
- The valuation of the green product is higher than the valuation of the brown product for customers in the green segment (driven by \( \kappa > 1 \)), and if \( v \in [1, 1 + (p_g - p_b)] \), then the valuation of the green product is greater than or equal to the valuation of the brown product for customers in the brown segment.

As described earlier, each of these two possibilities are incorporated in our analysis to account for differences in product categories (e.g., electric vehicles versus organic foods). The valuations of consumers in each market segment for brown and green products, along with

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9 Take EV-1 and Think Mobility electric vehicles introduced by General Motors (GM) and Ford, for example. The novel two-seat electric cars were expected to be market successes but both were ultimately taken off the market. The reason was that these vehicles appealed to only niche green customers (who purchased these vehicles primarily to help the environment) and could not attract the brown customers, because brown customers found electric vehicles’ need for constant recharging with few recharging locations too inconvenient and they were unwilling to drastically change their driving habits and expectations to accommodate electric cars (see, for example, Ottman, 2003; Palmieri, 2006, among others).

the price of each product and the proportion of consumers in each segment, are summarized in Table 1.

Consumers are rational and maximize their net utility, given by the difference of their valuation of the product and its price. That is, a brown consumer gets utility ($U_b = \theta - p_b$) from the brown product and utility ($U_g = \kappa \theta - p_g$) from the green product. A green consumer gets utility ($U_g = \kappa \theta - p_g$) from the brown product and utility ($U_b = \theta - p_b$) from the green product. The green consumers purchase the green product if $U_b < 0$ and $U_g > 0$. Otherwise, they purchase the brown product if $U_b > 0$. Likewise, a brown consumer purchases the brown product if $U_b > 0$ and $U_g < 0$, and green product if $U_b < 0$ and $U_g > 0$. Note that when there are both brown and green products in the market, a brown consumer would never purchase the green product, since $U_b = \theta - p_b < \theta - p_b = U_b$.

### 3.2. Cost structure

We denote the unit production cost of the brown and green products by $c_b$ and $c_g$, respectively. Regarding the brown products, we assume that there are no economies of scale so that unit cost $c_b$ is independent of the number of brown products produced. Green products are in general more expensive than brown products because their ingredients/raw materials tend to cost more than their more conventional counterparts. On the other hand, thanks to economies of scale due to high volumes, many green products today are competitively priced versus brown products. The concept of economies of scale is well understood in manufacturing. The more times a process is repeated, the more efficient it becomes and the lower its cost. Economies of scale on the production of green products has a critical role in analyzing the market conditions for green products; and we incorporate it into our model by assuming that $c_g = C - \gamma d_g$, where $C$ is the initial unit production cost of the green product, $\gamma > 0$ is a constant learning parameter and $d_g$ is the accumulated sales volume of the green product. We further assume that there is a fixed cost $F$ associated with the R&D, market research and other relevant expenses of introducing a new green product into the market.

### 3.3. Base scenario: single brown product

We first establish the firm’s profit maximization solution for his existing brown product to use as a benchmark. The firm currently offers a single brown product to the market at a price $p_b^* \text{ to maximize his profits.}$ Notice that when green product is not offered, the market can be represented via a single consumer type, because brown consumers and green consumers value the brown product at the same value $\theta$, implying that there is no market segmentation by consumer type in this case. Note that all consumers in this market are heterogeneous in terms of their valuation which is uniformly distributed over $[0, 1]$. Given that $d^*_b$ denotes the demand of the current brown product, the linear inverse demand function of the brown product can be written as $p_b^* = (1 - d^*_b)^*/2$. The firm’s profit function under current setting is then given by $\Pi = d^*_b(1 - d^*_b - c_b)$, which is maximized by $d^*_b = (1 - c_b)/2$. Based on that, the optimal price of the brown product is $p_b^* = (1 + c_b)/2$, yielding the optimal profit $\Pi^*_b = (1 - c_b)^2/4$.

### 3.4. Green product development scenario: green and brown products

Under this scenario, the firm expands his existing brown product line with a new green product. When both brown and green products are offered in the market, the firm prices them simultaneously to maximize his profits. In this case, the firm’s maximization problem is kinked with three possible demand regimes separated by two linear equations: $p_b = \kappa p_g$ and $p_b = p_g + \kappa - 1$ (see Fig. 1). Based on that the firm has two pricing options:

#### a. Low priced green product ($p_g < \kappa p_b$)

The firm can keep the price of the green product $p_g$ low to preclude price-sensitive green consumers from purchasing the brown product. Recall that existing brown product is offered at a price $p_b < p_g$, and green consumers buy the brown product only if $U_g > 0$ and $U_g > U_b$ (i.e., $\theta - p_b > 0$ and $\theta - p_g > \kappa \theta - p_g$), which translates to $p_b < \theta < (p_g - p_b)/\kappa$. Note that this condition holds as long as $p_g > \kappa p_b$, and by setting a lower price for the green product (i.e., $p_g < \kappa p_b$), the firm ensures that his brown product’s demand only comes from brown consumers (i.e., green consumers do not buy the brown product). Given that brown consumers do not buy the

### Table 1

<table>
<thead>
<tr>
<th>Product</th>
<th>Market segment</th>
<th>Market price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brown (B)</td>
<td>$\theta$</td>
<td>$\kappa \theta$</td>
</tr>
<tr>
<td>Green (G)</td>
<td>$\kappa \theta$</td>
<td>$p_g$</td>
</tr>
</tbody>
</table>

Note: It is assumed that $\nu < 1 + (p_g - p_b)$ and $\kappa > 1$.

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11 Since the firm is already offering a brown product in the market, our rationale is that he has already developed substantive expertise in this domain, and hence achieved the lowest possible unit cost associated with the production of the brown product.

12 The reason behind our factoring in the concept of economies of scale for the green product is that we investigate a capacity issue in our model. Note that our analysis focuses on how a capacity constraint moderates the pricing strategies of a firm in the pursuit of introducing a new green product into the market. To put it simply, the green product is not currently a part of the firm’s product portfolio, the firm is recognized for his brown offering (and traditional expertise) and so he has limited green expertise, making the consideration of economies of scale reasonable. It should also be noted that even though we employ a linear economies of scale function in our analysis, it can be relaxed to any non-linear function that strictly decreases with the cumulative production volume without any loss in structural insights.

13 We derive the inverse demand function from consumers’ utility function. We assume consumers’ willingness-to-pay (valuations) are distributed uniformly in the interval $[0, 1]$ and each consumer buys at most one unit. Therefore, for a total market size of 1, the quantity of brown product purchased at price $p_b$ is $d_b = 1 - p_b$. Then, the inverse demand function for the brown product is $p_b = 1 - d_b$.

14 Because of the one-to-one correspondence between price and demand, the optimization problem can be formulated either in terms of price or demand. We proceed with the latter for ease of interpretation.
green product when it is offered along with the brown product, the inverse demand functions of the brown and green products are formed as follows:

\[ p_b = 1 - \left( \frac{d_b}{1 - \beta} \right) \]  
\[ p_g = \kappa \left( 1 - \frac{d_g}{\beta} \right) \]  

(1) (2)

Note that the relative willingness-to-pay \( \kappa \) of green segment consumers has a direct effect on the price of the new green product. As the value of this parameter increases, the firm increases the price of its green product to take advantage of green consumers’ increased willingness-to-pay.

b. High priced green product (\( p_g > \kappa p_b \)). The firm can keep the price of the green product \( p_g \) high to reduce the negative impact of cannibalization on its existing brown product. As stated previously, when both products are available in the market, brown consumers do never prefer the green product over the brown product as \( U_b^g > U_g^b \). This means that they will only buy the brown product if \( U_b^g = \theta - p_b > 0 \) and nothing at all otherwise:

\[ d_b^g = (1 - \beta)(1 - p_b) \]  

(3)

In addition, the price sensitive green consumers will buy the brown product if \( U_b^g > 0 \) and \( U_g^g > 0 \) (i.e., \( p_b < \theta < (p_g - p_b)/(\kappa - 1) \)):

\[ d_g^c = \beta \left( \frac{p_g - \kappa p_b}{\kappa - 1} \right) \]  

(4)

Therefore, when \( p_g > \kappa p_b \), the brown product’s demand \( d_b \) comes not only from brown consumers but also from green consumers: \( d_b = d_b^g + d_g^c \). On the other hand, green consumers with valuation \( \theta \) such that \( (p_g - p_b)/(\kappa - 1) < \theta < 1 \) will buy the green product:

\[ d_g = d_g^c = \beta \left( 1 - \frac{p_g - p_b}{\kappa - 1} \right) \]  

(5)

We make the following assumption for this pricing option: \( p_g \leq p_b + \kappa - 1 \). This assumption ensures that the optimal solution satisfies the following properties: \( d_b^c > 0 \) and \( d_g^c > 0 \). This construction leads to the following linear inverse demand functions:

\[ p_b = 1 - d_b - d_g \]  
\[ p_g = 1 - d_b - d_g + (\kappa - 1) \left( 1 - \frac{d_g}{\beta} \right) \]  

(6) (7)

It is easy to see that the demand for the green product is 0 when \( p_g \geq p_b + \kappa - 1 \) and so we only consider the two pricing regimes: (i) \( p_g < \kappa p_b \); and (ii) \( \kappa p_b < p_g < p_b + \kappa - 1 \).

On the basis of these two pricing options, the firm maximizes its profits by solving the following problem:

\[
\max_{d_b, d_g \geq 0} \Pi_2 = d_b(p_b(d_b, d_g) - c_b) + d_g(p_g(d_b, d_g) - C + \gamma d_g) - F
\]  

(8)

4. Analysis

In this section, we evaluate different green product pricing choices of a firm initially with an infinite green product development capacity and then with a limited capacity.

4.1. Green product development under adequate capacity

Assume that production capacity is not binding; i.e., the firm can provide both brown and green products without a capacity limitation and so serve the total consumer demand. The firm introduces a new green product into the market at a fixed cost \( F \), and green and brown products are priced simultaneously to maximize profits. When \( p_g < \kappa p_b \), the optimal demand levels are those that maximize the profits obtained from both green and brown products as follows:

\[
\max_{d_b, d_g \geq 0} \Pi_2 = d_b(p_b(d_b, d_g) - c_b) + d_g(p_g(d_b, d_g) - c_g) - F
\]

\[ = d_b \left( 1 - \frac{d_b}{1 - \beta} \right) - c_b + d_g \left( \kappa \left( 1 - \frac{d_g}{\beta} \right) - C + \gamma d_g \right) - F \]  

(9)

On the other hand, when \( p_g > \kappa p_b \) and \( p_g < p_b + \kappa - 1 \), the optimal demand levels are those that maximize the profits obtained from both green and brown products as follows:

\[
\max_{d_b, d_g \geq 0} \Pi_2 = d_b(p_b(d_b, d_g) - c_b) + d_g(p_g(d_b, d_g) - c_g) - F
\]

\[ = d_b (1 - d_b - d_g - c_b) + d_g \left( 1 - d_b - d_g + (\kappa - 1) \left( 1 - \frac{d_g}{\beta} \right) - C + \gamma d_g \right) - F \]  

(10)

The following theorem characterizes the optimal demand levels of the brown and green products, and the optimal profit of the firm.

**Theorem 1.** Given that \( 0 < \beta < 1 \) and \( \kappa > 1 \), the solutions to the problems stated in (9) and (10) are:

**a.** If \( p_g < \kappa p_b \), then

\[
\begin{align*}
\left( d_b^*, d_g^* \right) &= \left( \frac{1 - \beta}{2}, -\frac{\beta (\kappa - C)}{2(\kappa - \beta \gamma)} \right), \\
\left( p_b^*, p_g^* \right) &= \left( \frac{1 + c_b \kappa (\kappa - C - 2\beta \gamma)}{2(\kappa - \beta \gamma)}, \frac{\beta (\kappa - C)}{2(\kappa - \beta \gamma)} \right), \\
\Pi_2 &= \left( \frac{1 - \beta}{2} \right)^2 + \frac{\beta (\kappa - C)^2}{4(\kappa - \beta \gamma)} - F.
\end{align*}
\]  

(11) (12) (13)

**b.** If \( \kappa p_b < p_g < p_b + \kappa - 1 \), then

\[
\begin{align*}
\left( d_b^*, d_g^* \right) &= \left( \frac{1 - c_g}{2}, -\frac{\beta (\kappa - 1 - C + c_g)}{2(\kappa - 1 - \beta \gamma)} \right), \\
\left( p_b^*, p_g^* \right) &= \left( \frac{1 + c_b (\kappa - 1)(\kappa - C - 2\beta \gamma) - \beta \gamma}{2(\kappa - 1 - \beta \gamma)}, \frac{\beta (\kappa - C)}{2(\kappa - 1 - \beta \gamma)} \right), \\
\Pi_2 &= \left( \frac{1 - c_g}{2} \right)^2 + \frac{\beta (\kappa - 1 - C + c_g)^2}{4(\kappa - 1 - \beta \gamma)} - F.
\end{align*}
\]  

(14) (15) (16)

**Proof.** See Appendix A. □

Theorem 1 provides insights into how introducing a green product might cannibalize the brown product’s sales in a marketplace where shoppers espouse environmental values. It is apparent that no matter what pricing strategy is adopted, the green product has a tendency to acquire customers from the firm’s existing brown offering. In both cases, the brown product’s market coverage drops since the green product attracts non-price sensitive customers with environmental attitudes who switch to the green product. Interestingly, when the green product is offered at a high-premium, in spite of losses in his brown product’s market demand, the overall market demand for the firm’s products remains same. In addition, the high premium-priced green product does not undercut the price of the existing brown product. As with the launch of the green product, the brown product retains its regular pricing scheme so that it is priced at the same level as before. This means that a high priced green product certainly cannibalizes brown product’s revenues but this does not necessarily translate to lower firm-level profits. Indeed, unless initial setup costs
are prohibitively high, the firm can calibrate those two offerings to its own strategic advantage.

**Proposition 1.** When \( p_g < \kappa p_b \), there exists a \( \gamma = \frac{C - \kappa \gamma}{\beta (1 - \gamma)} \) such that the firm enhances his market coverage by introducing a new green product into the marketplace if and only if \( \gamma > \gamma^* \). Otherwise, introduction of a new green product erodes firm’s market coverage.

**Proof.** See Appendix B. \( \square \)

The importance of Proposition 1 is that it shows the underlying role of scalability in reversing a possible decline in the firm’s market coverage (and even in increasing it) after a new green product with a relatively low price premium has been deployed. Proposition 1 states a threshold level \( \gamma^* \) on the scale parameter \( \gamma \) that drives down huge initial operating costs of the new green product as the scale of its production grows. Based on that, a low-premium green product improves overall market coverage of the firm, fostering profitable returns on investments in sustainability, only if it is sufficiently scalable (i.e., \( \gamma > \gamma^* \)). When it is difficult to build economies of scale or it takes too long to achieve scale production volumes (i.e., \( \gamma < \gamma^* \)), adopting the low-premium pricing regime would not only put the firm at an immediate and continuing cost disadvantage but also cause him to face continuing losses in market coverage. This might subsequently set a scale barrier to the market entry of the green product. In other words, failure to achieve economies of scale for the new green product that is offered at lower premium levels presents the most downside. It should also be noted that the threshold \( \gamma^* \) is a decreasing function of green consumers’ relative willingness-to-pay \( \beta \) and relative size of green segment \( \kappa \) but an increasing function of the initial unit production cost \( C \) of the green product. This means that as green customers weigh environmental criteria more heavily in their purchasing decisions and/or as the new green product mainstreams, it will be easier for the firm not only to build economies of scale but also to price the low-premium green product at a relatively higher value, allowing him to get the most value out of the green segment consumers while at the same time increasing his overall market coverage.

**Proposition 2.** Given that \( 0 < \beta < 1 \) and \( \kappa > 1 \), the firm is always better off offering his new green product at a high premium price rather than low, in which case he can also protect his current profits unless

\[
\beta < \frac{4F(\kappa - 1)}{4FY + (\kappa - C - 1 + \gamma c)^2}. \quad (17)
\]

**Proof.** See Appendix C. \( \square \)

Based on our discussion in Section 3.1, when only a brown product is in the market, green consumers cannot be differentiated, and hence the firm cannot capitalize on their willingness-to-pay. Launching a green product while selling a brown product, on the other hand, opens up the greener end of the market for the firm to pursue and helps him to exploit these consumers’ willingness-to-pay. Based on that, Proposition 2 underscores how critical the consumers’ product valuation is in deliberately losing a portion of consumers in one target segment while acquiring those in the other segment. Recall that consumers in the green segment are the types where cannibalization can be a real issue, because contrary to brown consumers who would never switch to a highly-priced green product, those of green consumers whose environmental sensitivity outweighs their price sensitivity would immediately buy the green product. Given that current consumers of the brown product cannot be differentiated with respect to their value statements, the firm ensures that his premium-priced green offering appeals to non-price conscious green segment he wants to attract while guaranteeing that it falls short for current price-sensitive green shoppers of the existing brown product. That is, the firm deliberately lessens the appeal of the new green offering to the brown product’s price-sensitive green consumers to retain a sustainable level of its profits and keep it above the fray.

### 4.2. Green product development under limited capacity

We now look at how a limited capacity affects the firm’s product-line decisions and characterizes the demand levels of the product(s) in its product portfolio. Suppose \( \Delta > 0 \) represents the total production capacity of the firm. We initially consider the impact of a scarce capacity \( \Delta \) on the base scenario where the firm offers a single brown product at a price \( p_b^* \) and then on the green product development scenario where the firm expands his existing product line with a new green product. Recall that when the firm offers a single brown product, the linear inverse demand function of the brown product is given by \( p_b = 1 - \delta b \), where \( \delta b \) denotes the demand of the brown product under a limited production capacity. Then, the firm’s profit maximization problem gets the following form:

\[
\begin{align*}
\max_{d_b} \quad & \hat{\Pi}_1 = \hat{d}_b(1 - \hat{d}_b - c_b) \\
\text{s.t.} \quad & \hat{d}_b \leq \Delta
\end{align*}
\]

(18)

The following theorem characterizes the optimal demand level and price of the brown product under a limited production capacity, as well as the optimal firm profits.

**Theorem 2.** Given \( \Delta > 0 \) and \( \Delta = (1 - c_b)/2 \), the solution to the problem stated in (18) is that if \( \Delta < \Delta^* \) then \( \hat{d}_b = \Delta, \hat{p}_b = 1 - \Delta \) and \( \hat{\Pi}_1 = \Delta(1 - c_b) - \Delta^2 \). Otherwise, \( \hat{d}_b = \hat{d}_b^* \), \( \hat{p}_b = \hat{p}_b^* \), and \( \hat{\Pi}_1 = \hat{\Pi}_1^* \). **Proof.** See Appendix D. \( \square \)

Theorem 2 shows that when production capacity is tight, the firm cannot produce adequate quantities of brown product and in response adjusts the market demand of it accordingly by embarking on a repricing strategy. In other words, the firm attempts to offset the brown offering’s losses caused by a decline in its market coverage through increases in its revenues. At this point, the firm can budget for some investment to increase his product development capacity through a comparison of the cost of investment in additional capacity and the value of additional consumer demand.

**Proposition 3.** Let \( t_b \) represent the unit cost of increasing existing production capacity. Given that current production capacity of the brown product is limited (i.e., \( \Delta < \Delta^* \)), the firm should invest in additional capacity, if and only if \( t_b < ((1 - c_b)/2) - \Delta \).

**Proof.** See Appendix E. \( \square \)

The condition in Proposition 3 represents the dominant impact of cost-side effects on the value of firm-level investment in additional capacity. It is observed that when the firm falls short for current consumers of his brown product, he tends to look for an investment of funds to increase his production capacity only if \( c_b \) is relatively small. On the other hand, high operating costs of the current brown product pushes the firm more toward no additional capacity investment, even if a significant portion of his current customers fall within the brown segment. In this case, the market-side factors seem to have no impact on the firm’s capacity investment decision. That is, whether reinvesting in existing brown product for cultivating additional revenue would be worth the effort or not is independent of how prominent the brown consumer segment is within the firm’s current consumer base compared to the green segment.

We now turn our attention to the green product development scenario with a production capacity \( \Delta \) such that \( \Delta > \Delta^* \) (i.e., the firm currently has sufficient capacity to offer his brown product and serve his existing consumer base), and exclusively focus on the demand region in Fig. 1 where \( p_g < \kappa p_b \) with the condition \( \gamma > \gamma^* \) detailed in Proposition 1. The underlying reason is as follows. Recall from our discussion in Theorem 1 that when the new green product is added into the portfolio, the market coverage of the current brown product
The linear inverse demand functions of the brown and green products are set with a price set just slightly more than the existing brown product, respectively. The number of green consumers (brown and green products under a limited production capacity when the new green product at so high premium levels that the green product is priced at an additional premium or low premium. That is, the firm can invest in additional capacity because the total demand (and so the total production volume) would remain same. On the other hand, as noted in Proposition 1, when the green product is offered at low premium levels so that \( p_g < \kappa p_b \), the overall market coverage of the green product grows if the green product is sufficiently scalable (i.e., \( \gamma > \bar{\gamma} \)), in which case the firm can fall short of production capacity and be required to invest in additional capacity.

Recall from Section 3.4 that when a green product enters the market with a price set just slightly more than the existing brown product, the linear inverse demand functions of the brown and green products are given by \( p_1 = 1 - (d_1(\beta - 1)) \) and \( p_g = \kappa (1 - (d_g(\beta)) \), respectively. Based on that, the optimal demand levels \( \hat{d}_b \) and \( \hat{d}_g \) under a limited capacity \( \Delta \) are those that maximize the firm profits obtained from brown and green products subject to a capacity constraint as follows:

\[
\max \hat{d}_b, \hat{d}_g \geq 0 \quad \hat{d}_b \left( 1 - \left( \frac{\hat{d}_b}{1 - \beta} \right) - c_b \right) + \hat{d}_g \left( \kappa \left( 1 - \frac{\hat{d}_g}{\beta} \right) - C + \gamma \hat{d}_g \right) - F \tag{19}
\]

s.t. \( \hat{d}_b + \hat{d}_g \leq \Delta \)

The following theorem characterizes the optimal demand levels of the brown and green products under a limited production capacity when the firm maintains the price premium of his green product relatively low.

**Theorem 3.** Given that \( p_g < \kappa p_b \), \( \gamma > \bar{\gamma} \) and \( \hat{\Delta} = (\kappa - C + (1 - \beta) \gamma) / (2\kappa - 2\beta \gamma) \), the solution to the problem stated in (19) is that if \( \Delta < \hat{\Delta} \), then

\[
(\hat{d}_b, \hat{d}_g) = \left( \frac{(1 - \beta)(2\Delta(\kappa - \beta \gamma) - \beta(\kappa - C + 1 + c_b))}{2\beta + 2(1 - \beta)(\kappa - \beta \gamma)}, \frac{\beta(2\Delta + (1 - \beta)(\kappa - C + 1 + c_b))}{2\beta + 2(1 - \beta)(\kappa - \beta \gamma)} \right). \tag{20}
\]

\[
(\hat{p}_b, \hat{p}_g) = \left( \frac{\beta((1 - \beta)(\kappa + 1 + C - c_b - 2\beta \gamma) + 2(\beta - \Delta))}{2\beta + 2(1 - \beta)(\kappa - \beta \gamma)}, \frac{\kappa((1 - \beta)(\kappa + 1 + C - c_b - 2\beta \gamma) + 2(\beta - \Delta))}{2\beta + 2(1 - \beta)(\kappa - \beta \gamma)} \right). \tag{21}
\]

\[
\hat{\Pi}_2^{*} = \frac{\beta(2\Delta + (1 - \beta)(\kappa - C + 1 + c_b))^2}{4(1 - \beta)(\beta + (1 - \beta)(\kappa - \beta \gamma))} + \frac{\Delta(1 - \beta)(1 - c_b) - \Delta^2}{(1 - \beta)} - F. \tag{22}
\]

Otherwise, \( (\hat{d}_b, \hat{d}_g) = (d^*_b, d^*_g), (\hat{p}_b, \hat{p}_g) = (p^*_b, p^*_g) \) and \( \hat{\Pi}_2 = \Pi_2^{*} \).

**Proof.** See Appendix F. \( \square \)

**Proposition 4.** Given that \( p_g < \kappa p_b \), \( \gamma > \bar{\gamma} \) and \( \hat{\Delta} = (\kappa - C + (1 - \beta) \gamma) / (2\kappa - 2\beta \gamma) \), the optimal output levels of the brown and green products tightly limited by a production capacity \( \Delta < \hat{\Delta} \) are less than those under a sufficiently available capacity. That is to say.

\[
d^*_b < d^*_g \quad \text{and} \quad \hat{d}^*_g < d^*_g. \tag{23}
\]

Furthermore, given that \( \bar{\zeta} = (C - c_b) / (\kappa - 1) \), the rate of decrease in the optimal demand level of the brown product is less than that of the green product if \( \bar{\zeta} > 1 \). For the values of \( \bar{\zeta} < 1 \), the demand of the brown product experiences a steeper decline compared to the green product. That is to say:

a. If \( \bar{\zeta} > 1 \), then \( \frac{d^*_b - \hat{d}^*_b}{d^*_b} < \frac{d^*_g - \hat{d}^*_g}{d^*_g} \).

b. If \( \bar{\zeta} < 1 \), then \( \frac{d^*_b - \hat{d}^*_b}{d^*_b} > \frac{d^*_g - \hat{d}^*_g}{d^*_g} \). \tag{24, 25}

**Proof.** See Appendix G. \( \square \)

Proposition 4 outlines how a capacity shortage reduces the output levels of both brown and green products within the portfolio that would shrink the profit pool available and that could result in significant collateral losses for the firm having launched a new green offering. At this point, while operating expenses of two products (i.e., \( C \) and \( c_b \)) weigh heavily with the corresponding production quantity decisions and allocation of limited production capacity, the degree of scalability of the green product (i.e., \( \gamma \)) is not instrumental at all. In other words, when resources are scarce, failure to scale should not be considered as one of the underlying factors that cause the firm to stumble after expanding its product line with a green product. That is said, green consumers’ relative willingness-to-pay for the green product compared to the brown product (i.e., \( \kappa \)) seems to further contribute to the dire straits that capacity shortage has already caused. Higher values of \( \kappa \) ensure that the value equation between a green product and its brown counterpart is suitably distinct in the mind of the green consumer. This means that when \( \kappa \approx 1 \), green consumers are unaware of the environmental attributes of the new green product and the product distinction is lost in their subjective world of interpretation. They simply see the green product as a brown product at a higher price, and the limited capacity eats into green product sales more than it damages those of the brown offering. The reason is that in such a market environment, the firm uses his brown product’s lower operating costs and lower prices to expand his market coverage at the expense of the green product. On the contrary, when a new

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16 The shoppers can be short on the facts about the green bona fides of products they buy because environmental benefits can be imperceptible, indirect or intangible in some end products. For example, consumers cannot see the emissions being reduced at the power plant when they use energy-efficient, water-conserving washers and dryers like they cannot see the capacity increase in the landfill when they recycle.
green product offers a sufficiently differentiated proposition to green consumers, constrained capacity leads to the green product “stealing” sales from the brown product at a higher rate.

5. Concluding remarks

Environmental strains are now causing consumers to trade up to more expensive but greener alternatives and many brown brands are losing share to these high-priced green rivals. Some managers are attempting to tackle the threat by launching new green products into the market, knowing that can destroy profits of their existing brands in the short term but enable them to suddenly open up a new market segment and gain a strong foothold in the green-end market. Many others are hoping that interest in green shopping is just a passing fad and holding onto their existing brown product lines, knowing that they can lose their environmentally sensitive consumers, often exhibiting high growth potential, who might never come back. Given how unpalatable both of these alternatives can be, many companies are finding a new green product launch tempting in the face of such a strategic conundrum. When it works, the combination of a green product and a brown product in the market would allow a firm to calibrate those two offerings to his own strategic advantage. However, one should also think about the hazards that render green brand failures, how thoroughly a new green product might cannibalize existing brown product sales and how a firm must divide his resources strategically at the very time when focus and investment are critical and/or when he should perhaps concentrate his efforts on the business at hand.

This paper provides strategic insights into expanding a product line already dedicated to a brown product with a new green offering while capturing capacity congestion for the existent production system and learning effects. The key managerial insights from our analysis are as follows. It is observed that rethinking the way how prices are set when the new green product is ready to hit the market can expand the market pie for the firm. The firm can use two pricing schemes for his new green product to extract what he can from every consumer segment in the market. Recall that green consumers are not passive price takers: they root out products with environmentally friendly attributes, do not deem their premium pricing unjust in general, and do not hesitate to abandon the non-green products that cross the line. In this market environment, it seems that rather than treating pricing as an optimization problem and pricing the green product mechanically in the pursuit of higher profits and exploiting green consumers’ willingness-to-pay, the firm can appropriate much of the value the customers in the marketplace will relinquish and maximize profits through providing a well-crafted discount on the premium, even though it does not necessarily result in a higher market coverage. The optimal choice here is determined by the market-related factors and characteristics of the new green product. For example, green and brown segment consumers may value the same green product differently, because what constitutes value for a given consumer segment can be quite different. While a brown consumer typically appreciates non-environmental values (e.g., functionality and style), a green consumer desires attributes environmentally sound. What appears in this study is that when the proportion of green consumers in the market is sufficiently high, the “right” price for the new green product should be a high premium, in which case the firm can also reverse the decline in his overall market coverage resulting from the potential cannibalization of the sales of his existing brown product by the new green product.

Our research in the light of observations summarized previously points out how a single inflexible pricing schedule can limit a firm’s ability to share value equitably with different customers or to overcome the threat of cannibalization after rolling out a new green product in a segmented market. The use of a two-level pricing structure under different support conditions can diminish the salience of excessive cannibalization and in fact completely avoid it at every time a new green product is rolled out in the market. This observation does not hold when the existent resources of the firm are scarce. Under limited production capacity, the firm cannot protect his products from cannibalization by revising the pricing structure and that in turn can spell the end of his brown product’s presence in the market or preclude him from launching the green product. Recall that green consumers choose on the basis of not only price but also environmental profile of a product, and even minor differences among options available to them can be worth investigating. Closely related to this, our analysis suggests that limited resources is most likely to lead to increasing cannibalization of the existing brown product when the new green product is clearly distinguishable from it in terms of tangible environmental features and capabilities.

Among the many possible extensions of our work, two seem promising. The model in this paper is built on a consumer market with two types of consumers, each exhibiting different purchasing habits, and on economies of scale. An interesting extension could be to look at the sales learning curve as a framework for helping managers develop thoughtful green brand launch strategies, plan allocation of their capacity more accurately and select appropriate market positioning. Despite being analogous to the manufacturing learning curve, the sales learning curve is separate from it, since it involves a never ending give-and-take between a firm and his customers. As customers adopt and use the product, the firm modifies both his offering and processes associated with producing and selling it through all of his consumer-facing departments. As observed in this paper, understanding where a brand or firm really stands on the two dimensions of green market size and the ability to differentiate on the basis of greenness can play a critical role in understanding whether a firm will be able to capitalize on becoming greener, underlining the importance of gathering information about consumer responsiveness and incorporating the collected data into the production process. A second extension would be to consider two firms engaged in a duopolistic competition where each firm can decide to supplement his current brown product with a new green product. In such a setting, it would be interesting to provide insights into whether there would be an equilibrium set of strategies for the firms and examine the key parameters which might result in such equilibrium.

Appendix A. Proof of Theorem 1

Assume that $p_g < \kappa p_b$. Then,

$$\Pi_2 = d_b \left( 1 - \left( \frac{d_b}{1 - \beta} - c_b \right) \right) + d_g \left( \kappa \left( 1 - \frac{d_g}{\beta} \right) - C + \gamma d_g \right) - F. \quad (A.1)$$

The first order conditions are:

$$\frac{\partial \Pi_2}{\partial d_g} = 1 - c_b - 2 \left( \frac{d_b}{1 - \beta} \right) = 0 \quad (A.2)$$
$$\frac{\partial \Pi_2}{\partial d_g} = \kappa - C - 2 d_g \left( \frac{\kappa}{\beta} - \gamma \right) = 0 \quad (A.3)$$

The second order derivatives can be written as:

$$\frac{\partial^2 \Pi_2}{\partial d_g^2} = \left( \frac{2}{1 - \beta} \right) \quad (A.4)$$
$$\frac{\partial^2 \Pi_2}{\partial d_b \partial d_g} = -2 \left( \frac{\kappa}{\beta} - \gamma \right) \quad (A.5)$$
$$\frac{\partial^2 \Pi_2}{\partial d_b \partial d_g} = 0 \quad (A.6)$$

Then, the Hessian of the objective function is given by...
Note that leading coefficient of the Hessian is negative and its determinant $|H| = 4\left(\frac{\beta}{\beta - \bar{y}}\right)$ is positive, if and only if $\kappa < \hat{\beta} \gamma > 0$. Therefore, given that $\kappa > \hat{\beta} \gamma$, the first order conditions derived in (A.2) and (A.3) yield the unique solution. Therefore, the optimal demand levels of the brown and green products under the low pricing strategy (along with their optimal prices) can be obtained as follows:

$$d^*_b = \frac{(1 - \beta)(1 - c_b)}{2} \quad (A.7)$$
$$d^*_g = \frac{\beta(\kappa - C)}{2(\kappa - \beta \gamma)} \quad (A.8)$$
$$p^*_b = \frac{\kappa}{2} \quad (A.9)$$
$$p^*_g = \frac{\kappa + C - 2 \beta \gamma}{2(\kappa - \beta \gamma)} \quad (A.10)$$

Substituting these optimal demand levels into the firm’s profit function given in (A.1), we derive the following optimal firm profit:

$$\Pi_2^* = \frac{(1 - \beta)(1 - c_b)^2}{4} + \frac{\beta(\kappa - C)^2}{4(\kappa - \beta \gamma)} - F \quad (A.11)$$

Now assume that $\kappa p_b < p_g < p_b + \kappa - 1$. Then,

$$\Pi_2^* = d_b(1 - d_b - d_g - c_b)$$
$$+ d_g \left(1 - d_b - d_g + (\kappa - 1) \left(1 - \frac{d_g}{\beta}\right) - C + \gamma d_g\right) - F \quad (A.12)$$

The first order conditions are:

$$\frac{\partial \Pi_2^*}{\partial d_b} = 1 - 2(d_b + d_g) - c_b = 0 \quad (A.13)$$
$$\frac{\partial \Pi_2^*}{\partial d_g} = \kappa - 2(d_b + d_g) - 2d_g \left(\frac{\kappa - 1}{\beta} - \gamma\right) - C = 0 \quad (A.14)$$

The second order derivatives can be written as:

$$\frac{\partial^2 \Pi_2^*}{\partial d_b^2} = -2 \quad (A.15)$$
$$\frac{\partial^2 \Pi_2^*}{\partial d_g^2} = -2 \left(1 + \frac{\kappa - 1}{\beta} - \gamma\right) \quad (A.16)$$
$$\frac{\partial^2 \Pi_2^*}{\partial d_b \partial d_g} = -2 \quad (A.17)$$

Then, the Hessian of the objective function is given by

$$H = \begin{pmatrix}
-2 \left(\frac{1}{\hat{\beta}} - \gamma\right) & -2 \\
-2 & -2
\end{pmatrix}.$$}

Note that as long as $\kappa - 1 - \beta \gamma > 0$, the leading coefficient of the Hessian is negative and its determinant $|H| = 4 \left(\frac{\beta}{\beta - \bar{y}}\right)$ is positive. Therefore, given that $\kappa > 1 + \beta \gamma$, the first order conditions derived in (A.13) and (A.14) yield the unique solution. Therefore, the optimal demand levels of the brown and green products under the low pricing strategy (along with their optimal prices) can be obtained as follows:

$$d^*_b = \frac{(1 - c_b)}{2} - \frac{\beta(\kappa - 1 - C + c_b)}{2(\kappa - 1 - \beta \gamma)} \quad (A.18)$$
$$d^*_g = \frac{\beta(\kappa - 1 - C + c_b)}{2(\kappa - 1 - \beta \gamma)} \quad (A.19)$$
$$p^*_b = \frac{1 + c_b}{2} \quad (A.20)$$
$$p^*_g = \frac{(\kappa - 1)(\kappa + C - 2 \beta \gamma) - \beta \gamma (1 + c_b)}{2(\kappa - 1 - \beta \gamma)} \quad (A.21)$$

Substituting these optimal demand levels into the firm’s profit function given in (A.12), we derive the following optimal firm profit

$$\Pi_2^* = \frac{(1 - c_b)^2}{4} + \frac{\beta(\kappa - 1 - C + c_b)^2}{4(\kappa - 1 - \beta \gamma)} - F \quad (A.22)$$

and the proof follows. $\square$

### Appendix B. Proof of Proposition 1

Recall from Theorem 1 that when $p_g < \kappa p_b$, the overall market coverage of the firm is given by

$$\frac{(1 - \beta)(1 - c_b)^2}{4} + \frac{\beta(\kappa - C)^2}{4(\kappa - \beta \gamma)} - F \quad (B.1)$$

Given that the brown product’s current market coverage is $(1 - c_b)/2$, the firm commands a higher market coverage by launching a new green product if and only if

$$\frac{(1 - \beta)(1 - c_b)^2}{4} + \frac{\beta(\kappa - C)^2}{4(\kappa - \beta \gamma)} \geq \frac{1 - c_b}{2} \quad (B.2)$$

Solving the above inequality for $\gamma$ shows that the condition holds if and only if $\gamma > \hat{\gamma}$ which is given by

$$C - \kappa c_b \leq \beta(1 - c_b) \quad (B.3)$$

and the proof follows. $\square$

### Appendix C. Proof of Theorem 2

Recall from Theorem 1 that the optimal profits under two distinct pricing options; (i) $p_g < \kappa p_b$ and (ii) $\kappa p_b < p_g < p_b + \kappa - 1$, have the following forms, respectively:

$$\Pi_2^* = \frac{(1 - \beta)(1 - c_b)^2}{4} + \frac{\beta(\kappa - C)^2}{4(\kappa - \beta \gamma)} - F \quad (C.1)$$
$$\Pi_2^{**} = \frac{(1 - c_b)^2}{4} + \frac{\beta(\kappa - C - 1 + c_b)^2}{4(\kappa - \beta \gamma - 1)} - F \quad (C.2)$$

The profit-maximizing firm is better off offering his new green product at a relatively high price if and only if $\Pi_2^{**} \geq \Pi_2^*$, or

$$\frac{(1 - c_b)^2}{4} + \frac{\beta(\kappa - C - 1 + c_b)^2}{4(\kappa - \beta \gamma - 1)} - F \geq \frac{(1 - \beta)(1 - c_b)^2}{4} + \frac{\beta(\kappa - C)^2}{4(\kappa - \beta \gamma)} - F \quad (C.3)$$

which simplifies to

$$\left((\kappa - C) - (1 - c_b)(\kappa - \beta \gamma)\right)^2 \geq 0. \quad (C.4)$$

This condition is always satisfied and so the proof follows for the first part. The second part of the proposition can be proved in a similar fashion. $\square$

### Appendix D. Proof of Theorem 2

Given that

$$\hat{\Pi}_1 = \hat{d}_b^2(1 - \hat{d}_b^2 - c_b) \quad (D.1)$$

the second order derivative of $\hat{\Pi}_1$ with respect to $\hat{d}_b^2$ is negative, meaning that $\hat{\Pi}_1$ is strictly concave in $\hat{d}_b^2$. We are interested in cases where $\hat{d}_b^2$ is strictly positive, and so the Lagrangean is

$$\mathcal{L}(\hat{d}_b^2, \lambda) = \frac{\hat{d}_b^2(1 - \hat{d}_b^2 - c_b) - \lambda(\hat{d}_b^2 - \Delta)}{\Delta} \quad (D.2)$$
Appendix F. Proof of Theorem 3

Given that $\Delta < \Delta$ and $\tau_b$ represents the unit cost of increasing production capacity, the cost of investment in additional capacity to meet existing consumer demand is given by $\tau_b(d_b^* - \Delta)$, or

$$
\tau_b \left( \frac{1 - c_b}{2} - \Delta \right).
$$

(E.1)

The value of additional consumer demand when capacity is just sufficiently increased (i.e., $\Pi^*_1 - \Pi^*_1$) is given by

$$
\frac{(1 - c_b)^2}{4} - \Delta (1 - c_b) + \Delta^2.
$$

(E.2)

Therefore, it is in the self-interest of the profit-maximizing firm to invest in additional capacity, as long as $\tau_b(d_b^* - \Delta) < \Pi^*_1 - \Pi^*_1$, or $\tau_b < (1/(2\delta_b)) - \Delta$, and the proof follows. □

Appendix E. Proof of Proposition 3

Recall from the proof of Theorem 1 that the Hessian of the profit function $\Pi^*_1$ is negative definite and so $\Pi^*_2$ is strictly concave in $(d_g, d_g)$ as long as $\kappa - \beta \gamma > 0$. We are interested in cases where $d_g$ and $d_g$ are strictly positive. The Lagrangian is

$$
L(d_b, d_g, \lambda) = d_b \left( 1 - \frac{d_b}{1 - \beta} - c_b \right) + d_g \left( \kappa \left( 1 - \frac{d_g}{\beta} \right) - C + \gamma \hat{d}_g \right) - F - \lambda(d_b + d_g - \Delta).
$$

(F.1)

with

$$
\frac{\partial L}{\partial d_b} = 1 - c_b - 2 \left( \frac{d_b}{1 - \beta} \right) - \lambda = 0. \quad \text{and}
$$

$$
\frac{\partial L}{\partial d_g} = \kappa - C - 2d_g \left( \frac{\kappa - \gamma}{\beta} \right) - \lambda = 0.
$$

(F.2)

(F.3)

Given that $\kappa - \beta \gamma > 0$, because profit function is concave, necessary and sufficient conditions for optimality are that $\partial L / \partial d_b = 0$ and $\partial L / \partial d_g = 0$, while $\lambda(d_b + d_g - \Delta) = 0$ and $\lambda \geq 0$.

Case 1. $d_b^* > 0$, $d_g^* > 0$ and $\lambda > 0$. Then, $d_b^* + d_g^* = \Delta$, and solving the first order conditions (F.2) and (F.3) simultaneously gives

$$
\lambda = \frac{(\kappa - C)(\beta - 1) - 2\delta_b(\kappa - \gamma)}{2(\kappa - \beta \gamma)}, \quad \lambda > 0 \quad \text{and only if} \quad \Delta < \frac{\kappa - C(1 - \beta)(\kappa - \gamma)}{2(\kappa - \beta \gamma)}.
$$

Case 2. $d_b^* > 0$, $d_g^* > 0$ and $\lambda = 0$. Solving the first order conditions (F.2) and (F.3) separately with $\lambda = 0$ gives $d_b^* = (1 - \beta)(1 - c_b)/2$ and $d_g^* = \beta(1 - c_b)/(2(\kappa - \beta \gamma))$. The condition $\lambda = 0$, or $d_b^* + d_g^* \leq \Delta$, holds only if $\Delta \geq \frac{\kappa - C(1 - \beta)(\kappa - \gamma)}{2(\kappa - \beta \gamma)}$.

The theorem follows from combining these conditions and cases, and substituting the corresponding optimal solutions into the profit function $\Pi^*_2$. □

Appendix G. Proof of Proposition 4

Given that $p_k < k p_b$ and $\hat{\Delta} = (\kappa - C + (1 - \beta)(C - c_b - \beta \gamma)) / (2\kappa - 2\beta \gamma)$, based on the expressions provided in (11) and (20), $d_b^* < d_b^*$ and $d_g^* < d_g^*$ if and only if

$$
\frac{1 - \beta + 2\gamma(\kappa - \beta \gamma)}{2\beta + (1 - \beta)(\kappa - \beta \gamma)} < \frac{(1 - \beta)(1 - c_b)}{2}.
$$

(G.1)

and

$$
\frac{\beta(2\Delta + (1 - \beta)(\kappa - C - 1 + c_b))}{\beta(2\Delta + (1 - \beta)(\kappa - \beta \gamma))} < \frac{(1 - \beta)(1 - c_b)}{2}. \quad \text{or} \quad \Delta < \hat{\Delta}.
$$

(G.2)

respectively. Simplifying both inequalities we obtain that these two conditions hold as long as

$$
\Delta < \frac{(1 - \beta)(1 - c_b) + \beta(\kappa - C)}{2(\kappa - \beta \gamma)}, \quad \text{or} \quad \Delta < \hat{\Delta}.
$$

(G.3)

This is what we had assumed in Theorem 3, and so the proof follows.

Regarding the second part of the proposition, the rate of decrease in the optimal demand level of the brown product is more than that of the green product, if and only if

$$
\frac{d_b^* - d_b^*}{d_b^*} > \frac{d_g^* - d_g^*}{d_g^*}.
$$

(G.4)

Substituting the optimal demand levels of the brown and green products given in (11) and (20) into the above inequality, this condition gets the following form:

$$
\frac{2\Delta(\kappa - \beta \gamma)(1 - c_b - \kappa - C)}{(\kappa - C)(1 - C_b)(\beta - 1)(\kappa - \beta \gamma)}
$$

$$
\frac{(1 - c_b - \kappa + C)(\beta - \kappa - C)(1 - c_b)(\kappa - \beta \gamma)}{(\kappa - C)(1 - C_b)(\beta - 1)(\kappa - \beta \gamma)}
$$

$$
\frac{(1 - \beta)(1 - c_b) + \beta(\kappa - C)}{2(\kappa - \beta \gamma)}, \quad \text{or} \quad \Delta \geq \hat{\Delta}.
$$

(G.5)

Now suppose that $\zeta = (C - c_b)/(\kappa - 1)$ and $\zeta < 1$. Then, the inequality provided in (G.5) holds if and only if

$$
\frac{2\Delta(\kappa - \beta \gamma)}{\beta(\kappa - c_b) + (1 - \beta)(1 - c_b)(\kappa - \beta \gamma)}, \quad \text{or} \quad \Delta > \hat{\Delta}.
$$

(G.6)

$$
\frac{(1 - \beta)(1 - c_b) + \beta(\kappa - C)}{2(\kappa - \beta \gamma)}, \quad \text{or} \quad \Delta \leq \hat{\Delta}.
$$

(G.7)

This is what we had assumed, and so the proof follows. □

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