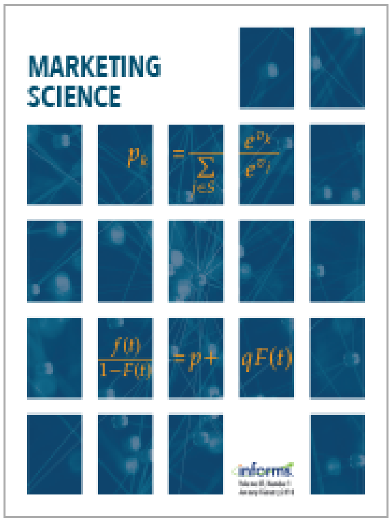

Marketing Science

Publication details, including instructions for authors and subscription information:
http://pubsonline.informs.org

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MARKETING SCIENCE
Vol. 32, No. 3, May–June 2013, pp. 510–521
ISSN 0732-2399 (print) | ISSN 1526-548X (online)

http://dx.doi.org/10.1287/mksc.2013.0774

Can Commonality Relieve Cannibalization in Product Line Design?

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The predominant perception on commonality strategy in product line design is that it entails a trade-off decision for a firm between cost savings and product differentiation. Adopting the commonality strategy may lower a firm's manufacturing costs, but it blurs the distinction between products targeting different consumer segments and makes consumer switching between products more likely such that cannibalization is always intensified. We show that this view in the literature is based on a crucial assumption that the quality valuation of one consumer segment is greater than that of another segment for all product attributes; i.e., one segment's preference structure dominates the other segment's preference structure. In this paper we consider the case of a nondominating preference structure where each segment has an attribute it values more than the other segment does. Interestingly, we show that the effect of commonality strategy is more diverse in this nondominating preference structure and that commonality can actually relieve cannibalization in the product line design. This finding gives rise to a previously unrecognized opportunity for firms to redesign their product lines to improve profits.

Key words: marketing/operations interface; product line design; commonality; nondominating preference structure; price discrimination
History: Received: April 24, 2011; accepted: December 28, 2012; Preyas Desai served as the editor-in-chief and David Godes served as associate editor for this article. Published online in *Articles in Advance* March 21, 2013.

1. Introduction

One important decision marketing and manufacturing managers must make when designing their product lines is whether to use product-specific components for individual products or common components for the entire product line. Although using common components for the product line significantly reduces the manufacturing costs, marketing and operations scholars have cautioned against using the commonality strategy by showing that commonality dilutes product differentiation and intensifies product cannibalization within the product line (Kim and Chhajed 2000, Desai et al. 2001, Krishnan and Gupta 2001, Heese and Swaminathan 2006). This paper builds on the past literature on product commonality and contributes to it by showing that such a predominant perception of commonality may not be valid in many markets and product categories. In fact, the commonality strategy can even alleviate production cannibalization in the product line.

The standard approach to studying the effects of product commonality is to consider a market with vertical consumer heterogeneity in which there are two consumer segments. Consumers in one segment (i.e., the high segment) value all product attributes more so than consumers in the other segment (i.e., the low segment). Such a dominating consumer preference framework captures some situations of marketing practice, but it neglects many other market situations. For example, consumer preference may be nondominating such that consumers in one segment may place a higher value on a particular product attribute than consumers in another segment, who maybe value another attribute more. Because different consumer segments place higher values on different product attributes, the nondominating consumer preference structure also captures horizontal consumer heterogeneity. In other words, within the same attribute consumers are vertically heterogeneous, whereas across different attributes consumers are horizontally differentiated. This nondominating consumer preference framework is quite different from the traditional approach of modeling consumer vertical/horizontal heterogeneity (Desai 2001). In our framework, consumers are vertically differentiated for a particular attribute but are opposite in the importance they give to the two vertical attributes.

There are many markets that satisfy the nondominating consumer preference structure. We list some of them below.

1. In the auto market, some working-class consumers often rely more on the functionality of cars

such that they can commute to work and shuttle their children to school; rich consumers who have multiple means of transportation often value luxury add-on features instead.

2. For electronics products such as the iPod, functionality-oriented consumers value the storage space, whereas style-driven consumers value the design and the small size.

3. In the banking industry, rich consumers are more concerned with security and capital growth; working-class consumers often value more the convenience of banking services so that they can pay their bills or get small amounts of cash conveniently.

4. Bags that are elegant and make a great professional impression with room for a laptop or documents are of greater value to business travelers than to leisure travelers, who often value the size and capacity of the bags more.

5. In the food market, some consumers place more value on product taste, whereas other consumers place more value on the health aspects of products.

6. In many markets, some consumers appreciate the greenness of products and are willing to pay more for green attributes such as recycled materials in paper, organic elements in fruit, or low-emission cars; other consumers may pay more for the products' more traditional attributes such as glossiness in paper, sweetness in fruit, and space in cars (see also Calcott and Walls 2000, 2005).

In this paper, we study the effects of product commonality on a firm in a market where consumer preference structure is nondominating, and we contrast the results with those obtained in past literature in a market with a dominating consumer preference structure. We provide answers to the following questions facing marketing managers: (1) How should a firm design its product line, taking into consideration the consumer preference structure? (2) When should a firm adopt a product commonality strategy in a market where consumer preference is nondominating? (3) When a firm adopts a product commonality strategy, how does that affect product cannibalization in a product line? Our answers to these questions will benefit marketing managers in designing their product lines and in deciding whether to embrace product commonality.

In our model, the firm designs a product line of two products with two attributes each and sells these products to two consumer segments. The two segments are differentiated such that each values one product attribute more than the other segment does. The firm has to decide whether to adopt a commonality strategy. A commonality strategy can be exemplified by Honda using the same platform or hybrid technology for both its Acura and Accord models (Desai et al. 2001); Apple improving storage space on its devices by providing its iCloud service for consumers of both iPod Nano and iPod Classic; banks offering convenient online banking services with bill payment options and accounts transfer services; or manufacturers in many product categories using standard technology, material, or design in their product lines. In our model, when the firm does not adopt a commonality strategy, it can offer all attributes freely at different levels in the products. However, when the firm adopts a commonality strategy, one of the attributes is offered at the same level in both products; we refer to it as the *common attribute*. In addition, the other attribute is offered at different levels in each product; we refer to it as the *custom attribute*. We derive the firm's specifications of optimal product line design with and without commonality and compare them to determine the effects of product commonality on the design of the product line.

We contribute to marketing literature by showing that adopting the commonality strategy does not necessarily intensify the degree of cannibalization in a product line and can indeed alleviate it. Our results also complement the results in past literature that show that product commonality intensifies cannibalization in the product line (Kim and Chhajed 2000, Desai et al. 2001, Krishnan and Gupta 2001, Heese and Swaminathan 2006). We show that commonality can alleviate product cannibalization in a product line in a market with a nondominating consumer preference structure. Consequently, in such markets, marketing managers should embrace commonality without worrying about product cannibalization within the product line while still enjoying the cost saving from commonality. Therefore, when marketing managers make decisions on product commonality, they need to study whether the consumer preference structure is similar to the one in this paper or the one described in the past literature studying dominating consumer preference structure (Kim and Chhajed 2000, Desai et al. 2001, Krishnan and Gupta 2001, Heese and Swaminathan 2006).

In addition, we show that the way a firm designs a product line in a market with a nondominating consumer preference structure should be significantly different from the way it designs its product line in a market with a dominating consumer preference structure. In the latter market, consumers in one segment (i.e., the high segment) value both product attributes more than consumers in the other segment do. In this case, the firm should optimally design a product where both product attributes are of high quality for the high segment and another product where both attributes are of low quality for the low segment; i.e., the product offered to the high segment dominates the product offered to the low segment for both attributes. In contrast, in a market with a nondominating consumer preference structure, the firm should optimally design the product line such that each consumer segment gets a product where the attribute it values is of high quality; thus no one product dominates. Because neither product is dominating, consumers in one segment may have the incentive to buy the product targeting the other segment if the price is attractive.

Furthermore, we show how the effect of product commonality's on product cannibalization depends on consumer preference structure. In a market with a dominating consumer preference structure, if the firm adopts the commonality strategy for one of its attributes, the designed quality of the common attribute will be the same for both segments; product differentiation is now based only on the other attribute. Consequently, the product offered to the high segment becomes less dominating compared with the product offered to the low segment. Because of the diminished product differentiation, consumers are more likely to switch to the product designed for the other segment if the price is attractive, thus intensifying cannibalization in the product line. In contrast, in a market with a nondominating consumer preference structure, if the firm adopts the commonality strategy and the cost savings is sufficiently high, the quality of the common attribute can be higher than the quality of that same attribute in either product before commonality. Thus the product where the other attribute is of higher quality becomes the dominating product. Therefore, after the firm adopts the commonality strategy, there is a greater differentiation in the consumers' utilities for products. For consumers in the segment where the common attribute is not the more valued attribute, commonality and the associated increase in the quality level of the less preferred attribute reduce their incentives to switch to the product targeted to the other segment, thus alleviating product cannibalization in the product line.

This paper is closely related to the product line design literature in marketing. Whereas some marketing researchers applaud firms' efforts to offer different products in their product lines to improve consumer demands (Kotler 2002), target different consumer segments (Villas-Boas 2004a), or better utilize firms' manufacturing capability or obtain more retail shelf space (Lancaster 1979, Quelch and Kenny 1994, Aaker 1996), other scholars express concerns for the possible cannibalization problems in product lines (Mussa and Rosen 1978, Moorthy 1984, Moorthy and Png 1992). In these papers, products are differentiated along a single quality-type (vertical) attribute, and consumers' heterogeneous willingness to pay for quality can be ordered along that single dimension. Desai (2001) studies a mixed vertical/horizontal model where consumers in either a high or a low segment are also horizontally differentiated on their taste preferences. Our paper captures vertical and horizontal consumer heterogeneity in a different way; consumers are vertically heterogeneous on both product attributes. However, across attributes, consumers in different segments are horizontally differentiated on the importance of the two vertical attributes. In Desai (2001), consumers do not agree on their taste preferences and the strength of the disagreement is higher for the higher valuation segment. In our model all consumers in a segment agree on their preferences, but the segment that values an attribute higher may not consistently be the same segment for every attribute.

This paper is also very closely related to the marketing and operations literature that examines the effects of adopting a commonality strategy on the trade-off between cost savings and reduced product differentiation as a result of the use of common components across products. Several papers address and integrate the demand-side effect of commonality with the supply-side effect of commonality. Krishnan and Gupta (2001) discuss the design of a reusable platform in a product line design. Kim and Chhajed (2000) consider a model in which two products are offered to the market using a combination of common and custom designs. While Krishnan and Gupta (2001) and Kim and Chhajed (2000) discuss the demand- and supply-side effects of commonality, their models deal only with a single attribute. Desai et al. (2001) study the issue of product commonality with two components and show that the primary benefit of commonality comes from savings in design costs. Heese and Swaminathan (2006) consider a model similar to that of Desai et al. (2001), but they examine a general cost saving function for commonality. Both Desai et al. (2001) and Heese and Swaminathan (2006) show that commonality intensifies cannibalization in the product line in a market with dominating consumer preference structure. Although our paper is inspired by Desai et al. (2001), it is different in some important respects. We model the effect of cost savings derived from commonality when quality is endogenous and consider the market with nondominating preference structure. Both these modeling constructs are instrumental in the derivation of our main results. Our focus is on establishing that the commonality strategy can indeed relieve product cannibalization in such a market. Thus the firm can reduce costs and product cannibalization at the same time.

2. Model

We consider a firm selling to a market with two consumer segments, $i = 1, 2$ (Desai et al. 2001, Heese and

Swaminathan 2006). The size of the market is normalized to 1, and the size of segment i is denoted by r_i. The firm has a product line of two products with two vertical attributes for which more is always better for all consumers. Segment i's valuation of attribute j is denoted by w_{ij}, $j = k, t$, and the level of attribute $j = k, t$ offered in product x is denoted as q_{xj}. (See Table 1 for the notation used in this paper.) Therefore, the utility for a consumer in segment i for product x, $x = 1, 2$ is denoted by $w_{it}q_{xt} + w_{ik}q_{xk}$. The firm's price for product x is P_x. Between the two segments, one segment is said to dominate the other in terms of preference structure if $w_{1k} > w_{2k}$, $w_{1t} > w_{2t}$ or $w_{1k} < w_{2k}$, $w_{1t} < w_{2t}$; neither segment is dominating if $w_{1k} > w_{2k}$, $w_{1t} < w_{2t}$ or $w_{1k} < w_{2k}$, $w_{1t} > w_{2t}$. When the firm adopts the commonality strategy, one attribute is offered at the same level in both products. For instance, in the example of iPod Classic and iPod Nano, when Apple provides its iCloud service, the storage attribute becomes the same for both products. We refer to this as the *common* attribute and assume it is attribute k; we refer to the other attribute t, offered at different levels in each product, as the *custom* attribute. When the firm does not adopt the commonality strategy, it can offer both attributes at different levels in different products. Note that in practice, the attribute that can be made common is very often out of the control of marketing managers and is instead decided by external factors such as the technology available. For example, the innovation of iCloud has given Apple the opportunity to make storage space common for consumers who use either iPod Nano or iPod Classic. Similarly, the Internet has made it possible for banks to make convenient online banking common for all consumers.

We assume the cost of offering an attribute to be convex in quality so that it is increasingly costly to offer better quality (Moorthy 1984, Desai et al. 2001, Heese and Swaminathan 2006). For mathematical tractability, we assume a quadratic function, $c_j q_{ij}^2$, where c_j is a cost coefficient of an attribute. When an attribute k is common, we assume that the cost is reduced by a constant fraction so that its cost coefficient decreases to $c_k(1-\alpha_k)$, where $0 \le \alpha_k < 1$. The cost saving parameter, α_k, captures the supply-side benefits in design, production, and operations that are due to scale economics and includes savings from a simpler product design and development process, as well as a subsequent simplification in manufacturing, inventory management, and material outsourcing processes (Gerchak et al. 1988, Smith and Reinertsen 1991, Lee and Billington 1994, Meyer and Lehnerd 1997, Sanderson and Uzumeri 1997, Muffatto 1999, Fixson 2007, Salvador 2007). Unlike Heese and Swaminathan (2006), we focus only on cost reduction as a result of scale economics and savings as a result of component rationalization, and not on additional operational effort to reduce the marginal cost. The essence of this multiplicative form of cost reduction is that the cost saving directly influences the level of common attribute and, consequently, the firm's revenue through consumer segments' valuation of products.[1] The functional form of cost saving we use is probably the most simplistic form that allows us to clearly focus on the effect of the consumer preference structure on the commonality strategy. The model setup on cost saving is deliberately consistent with past literature (Kim and Chhajed 2000, Desai et al. 2001, Heese and Swaminathan 2006), which allows us to contrast the results in this paper with those obtained in the past. Throughout this paper, we will also denote the offered level of the common attribute by $q_k = q_{1k} = q_{2k}$. The firm maximizes its profit by choosing optimal attribute levels and prices as follows:

(CPD)

$$\max_{P_1, P_2, q_{1t}, q_{2t}, q_k} \left\{ r_1\{P_1 - (c_t q_{1t}^2 + c_k(1-\alpha_k)q_k^2)\} + r_2\{P_2 - (c_t q_{2t}^2 + c_k(1-\alpha_k)q_k^2)\} \right\}$$

subject to

$$w_{1t}q_{1t} + w_{1k}q_k - P_1 \ge w_{1t}q_{2t} + w_{1k}q_k - P_2, \tag{1}$$

$$w_{2t}q_{2t} + w_{2k}q_k - P_2 \ge w_{2t}q_{1t} + w_{2k}q_k - P_1, \tag{2}$$

$$w_{1t}q_{1t} + w_{1k}q_k \ge P_1, \tag{3}$$

$$w_{2t}q_{2t} + w_{2k}q_k \ge P_2, \tag{4}$$

$$q_{1t} \ge 0, \; q_{2t} \ge 0, \; q_k \ge 0.$$

In the above formulation, the firm maximizes its profits from the two segments. Constraints (1) and (2) are self-selection constraints, and constraints (3) and (4) are participation constraints for the first and second

Table 1 Notation

Variable	Description
r_i	Size of segment i, $i = 1, 2$
w_{ij}	Part-worth of customer segment i for attribute $j = k, t$
q_{ij}	Amount of attribute j offered in a product for segment i
c_j	Cost coefficient of attribute j
α_j	Cost savings associated with attribute j if it is common, $0 \le \alpha_j < 1$
P_i	Price of product offered to segment i
R_j	$= r_1(w_{1j} - w_{2j})/r_2 w_{2j}$
π	Profit or product design strategy

[1] If cost saving takes an additive form, then it reduces the total production cost, but it does not directly influence either the level of common attribute or the firm's revenue (see §3.1 in Heese and Swaminathan 2006). To demonstrate the effect of commonality strategy and its associated cost saving on the notion of cannibalization and the firm's revenue, it is essential to use a multiplicative form of the cost saving function.

segments, respectively. When the firm does not adopt the commonality strategy, it will maximize its profit in a similar manner using q_{1k} and q_{2k} instead of q_k.

In a standard solution to the problem above with self-selection and participation constraints, the firm extracts all surpluses from at least one segment while reducing the product price for the other segment below the reservation price to prevent switching to the other product. The amount of price reduction offered in an optimal solution equals the amount of surplus it gets from the other would-be product so that the switching segment becomes indifferent to either product. The notion of cannibalization within a product line can be captured through this price reduction (or equivalently, through the amount of surplus that must be offered to the switching segment). We say that commonality strategy *intensifies* (*relieves*) cannibalization if the firm has to increase (decrease) the amount of price reduction to avoid consumer switching.

3. Analysis

We use the standard solution approach to solve the models of product design where price and quality are determined by relaxing self-selection and participation constraints of the consumer segments (Moorthy 1984, Desai et al. 2001, Heese and Swaminathan 2006). In those models, the dominating preference structure assumed ensures that the high-end segment will switch to lower-end products so that the high-end segment's self-selection constraint and the lower-end segment's participation constraint are always binding in the optimal solutions. In a market with the nondominating preference structure, however, the segments' switching does not occur unilaterally. Nevertheless, in equilibrium, the firm can always optimally increase product prices until it extracts all surpluses from at least one segment in equilibrium.

In the following analysis, we follow the past literature and, without loss of generality, assume that the first segment's self-selection constraint is binding and that the second segment's participation constraint is binding in equilibrium:[2]

$$\frac{r_1}{r_2} \le \min\left\{\frac{c_k w_{2t}(w_{1t}-w_{2t})+c_t w_{2k}(w_{1k}-w_{2k})}{c_k(w_{1t}-w_{2t})^2+c_t(w_{1k}-w_{2k})^2},\right.$$
$$\left.\frac{c_k(1-\alpha_k)w_{2t}(w_{1t}-w_{2t})+c_t w_{2k}(w_{1k}-w_{2k})}{c_k(1-\alpha_k)(w_{1t}-w_{2t})^2}\right\}.$$

[2] The first term ensures the self-selection constraint is binding for the first segment and the participation constraint is binding for the second segment in the case without commonality; the second term ensures the same in the case with commonality. Please refer to the proof in the appendix for detailed derivations. Note also that the interior solution we consider is infeasible for the case with the second segment dominating ($w_{1t} < w_{2t}$ and $w_{1k} < w_{2k}$).

Note that as we proceed with our analysis, we can not use the term "high segment" and "low segment" as in past literature to describe our segments because neither segment dominates in the current model. Solving the optimal solution to the problem (CPD), we obtain the optimal quality and profit for the firm with the commonality strategy as follows:[3]

$$q_{1t}^C = \frac{w_{1t}}{2c_t}, \quad q_{2t}^C = \frac{w_{2t}(1-R_t)}{2c_t}, \quad q_k^C = \frac{w_{2k}}{2c_k(1-\alpha_k)},$$
$$\pi^C = \frac{r_1 w_{1t}^2 + r_2 w_{2t}^2(1-R_t)^2}{4c_t} + \frac{w_{2k}^2}{4c_k(1-\alpha_k)},$$
$$\text{where } R_t = \frac{r_1(w_{1t}-w_{2t})}{r_2 w_{2t}} < 1.$$

Note that the quality of the common attribute is the same for both products when the firm adopts the commonality strategy. The quality difference for the custom attribute is $q_{1t}^C - q_{2t}^C = (w_{1t}-w_{2t})/2c_t r_2 > 0$ if $w_{1t} > w_{2t}$ and $q_{1t}^C - q_{2t}^C = (w_{1t}-w_{2t})/2c_t r_2 < 0$ if $w_{1t} < w_{2t}$. In contrast, when the firm does not adopt the commonality strategy, the optimal quality and profit for the firm are given as follows (Kim and Chhajed 2002):

$$q_{1t}^{NC} = \frac{w_{1t}}{2c_t}, \quad q_{2t}^{NC} = \frac{w_{2t}(1-R_t)}{2c_t}, \quad q_{1k}^{NC} = \frac{w_{1k}}{2c_k},$$
$$q_{2k}^{NC} = \frac{w_{2k}(1-R_k)}{2c_k},$$
$$\pi^{NC} = \frac{r_1 w_{1t}^2 + r_2 w_{2t}^2(1-R_t)^2}{4c_t} + \frac{r_1 w_{1k}^2 + r_2 w_{2k}^2(1-R_k)^2}{4c_k},$$
$$\text{where } R_k = \frac{r_1(w_{1k}-w_{2k})}{r_2 w_{2k}} < 1.$$

When the firm does not adopt commonality, the quality levels of both attributes are different for the products. The quality differences for the attributes are given by $q_{1t}^{NC} - q_{2t}^{NC} = (w_{1t}-w_{2t})/2c_t r_2$ and $q_{1k}^{NC} - q_{2k}^{NC} = (w_{1k}-w_{2k})/2c_k r_2$. Therefore, in a nondominating consumer preference structure, we have $q_{1t}^{NC} - q_{2t}^{NC} > 0$ and $q_{1k}^{NC} - q_{2k}^{NC} < 0$ if $w_{1k} < w_{2k}$ and $w_{1t} > w_{2t}$, and $q_{1t}^{NC} - q_{2t}^{NC} < 0$ and $q_{1k}^{NC} - q_{2k}^{NC} > 0$ if $w_{1k} > w_{2k}$ and $w_{1t} < w_{2t}$. Note that without commonality, each segment gets a product where the attribute it prefers is of high quality. With commonality, the custom product's quality does not change, but the quality of the common attribute increases for one or both segments. In Table 2, we compare the quality levels of the common attributes before and after the firm adopts the commonality strategy, and we provide the subsequent changes in product prices and consumer surplus.

[3] We use π to represent both the product design strategy and profit. We use superscripts NC and C to denote the optimal solutions under noncommonality and commonality strategies, respectively.

Table 2 Changes in Consumers' Utility, Surplus, and Product Prices Caused by Commonality

	$w_{1k} > w_{2k}$		$w_{1k} < w_{2k}$	
Condition =	$\alpha_k < (w_{1k} - w_{2k})/w_{1k}$	$\alpha_k > (w_{1k} - w_{2k})/w_{1k}$	$\alpha_k < r_1(w_{2k} - w_{1k})/(w_{2k} - (r_1 w_{1k}))$	$\alpha_k > r_1(w_{2k} - w_{1k})/(w_{2k} - (r_1 w_{1k}))$
Product quality [a] =	$q_{1k}^{NC} > q_k^C > q_{2k}^{NC}$	$q_k^C > q_{1k}^{NC} > q_{2k}^{NC}$	$q_{2k}^{NC} > q_k^C > q_{1k}^{NC}$	$q_k^C > q_{2k}^{NC} > q_{1k}^{NC}$
First product price	↓	↓↑	↓↑	↑
Second product price	↑	↑	↓	↑
First segment's utility	↓	↑	↑	↑
Second segment's utility	↑	↑	↓	↑
First segment's surplus	↑	↑	↑	↓
Second segment's surplus	—	—	—	—

[a]Where $q_{1k}^{NC} = w_{1k}/2c_k$, $q_{2k}^{NC} = (w_{2k}(1 - R_k))/2c_k$, and $q_k^C = (w_{2k})/(2c_k(1 - \alpha_k))$.

We next compare the firm's profit with and without product commonality and derive the conditions under which the firm chooses to adopt commonality.

Proposition 1. *The firm optimally adopts product commonality ($\pi^C > \pi^{NC}$) and makes attribute k common if $\alpha_k > r_1(w_{2k} - w_{1k})^2/(r_1(w_{2k} - w_{1k})^2 + r_2 w_{2k}^2)$, regardless of the preference structure.*

Proposition 1 indicates that the commonality strategy improves the firm's profitability when the associated cost saving is relatively significant, which is consistent with the observation made by Desai et al. (2001). In our model, although a specific attribute is assumed to be common, profitability of commonality strategy can be ensured regardless of which segment values the common attribute more; i.e., $w_{1k} > w_{2k}$ or $w_{1k} < w_{2k}$. However, the attribute that becomes the common one often depends on external factors and is therefore out of the control of marketing managers. Examples include the innovation of iCloud for iPod and the advances of the Internet for online banking. If the firm can endogenously select the common attribute, then that selection will be driven by different cost savings in making different attributes common (i.e., the cost savings in providing iCloud versus the cost savings in providing the same style for both iPod Classic and iPod Nano), and the firm will simply pick the one attribute that provides the highest amount of profit between the two.

We next analyze the effect of product commonality on the degree of cannibalization within the product line by comparing consumer surpluses before and after the firm adopts the commonality strategy (S^C and S^{NC}). The consumer surplus change as a result of the commonality is captured with $\Delta S = S^C - S^{NC}$. The most interesting results are summarized in Proposition 2 and are illustrated in the top half of Figure 1.

Proposition 2. *When the firm optimally adopts product commonality ($\pi^C > \pi^{NC}$) and the common attribute is the one valued more by the second segment (the segment whose participation constraint is binding in equilibrium) in the nondominating consumer preference structure ($w_{1k} < w_{2k}$), product commonality intensifies the cannibalization in the product line ($\Delta S > 0$) if*

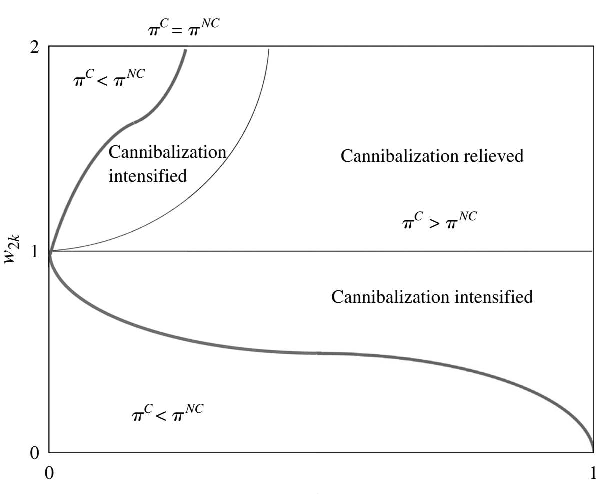
$$\frac{r_1(w_{2k} - w_{1k})^2}{r_1(w_{2k} - w_{1k})^2 + r_2 w_{2k}^2} < \alpha_k < \frac{r_1(w_{2k} - w_{1k})}{w_{2k} - r_1 w_{1k}}$$

and relieves cannibalization ($\Delta S < 0$) if

$$\frac{r_1(w_{2k} - w_{1k})}{w_{2k} - r_1 w_{1k}} < \alpha_k \le 1 - \frac{c_t w_{2k}(w_{2k} - w_{1k})}{c_k w_{2t}(w_{1t} - w_{2t})(1 - R_t)}.$$

Interestingly, Proposition 2 shows that product commonality can actually relieve cannibalization in the product line when it is accompanied by sufficiently high cost savings. This result complements the widespread results in the past literature on product commonality showing that product commonality always intensifies cannibalization (Kim and Chhajed 2000, Desai et al. 2001, Krishnan and Gupta 2001, Heese and Swaminathan 2006). Our analysis shows that the consumer preference structure considered in this paper drives this different result.

Figure 1 Regions Where the Commonality Strategy Intensifies ($\Delta S > 0$) or Relieves ($\Delta S < 0$) Cannibalization



Note. Drawn with $w_{1k} = 1$ and $r_1/r_2 = 0.5$.

The intuition behind our result is as follows. In the dominating consumer preference structure studied in the past literature, consumers in one segment (typically called the *high segment*) value both attributes higher than consumers in the other segment (typically called the *low segment*). Therefore, the firm will optimally design a product for the high segment where both attributes are of higher quality than the attributes of the product for the low segment. This leads to high product differentiation for both attributes between the products offered to different consumers, and this high differentiation prevents the high segment from switching to the product targeting the low segment. When the firm adopts the commonality strategy, it has to offer the same quality for the common attribute. Now the products targeting different segments differ only in one attribute, the custom attribute, and product differentiation is reduced. With reduced product differentiation within the product line, the high segment consumers are more likely to switch to buy the product targeted for the low segment, thus intensifying cannibalization. This is the result obtained from the past literature (Kim and Chhajed 2000, Desai et al. 2001, Krishnan and Gupta 2001, Heese and Swaminathan 2006).

In a nondominating consumer preference structure analyzed in our paper, consumers in each segment place more value on a different product attribute. Therefore, the firm will design a product for each segment where the attribute valued higher by that particular segment ($q_{1t}^{NC} - q_{2t}^{NC} > 0$ and $q_{1k}^{NC} - q_{2k}^{NC} < 0$ if $w_{1k} < w_{2k}$ and $w_{1t} > w_{2t}$) is of high quality. In other words, the products do not dominate each other, and to some extent, the benefit of having one attribute of high quality can be canceled out by having the other attribute of low quality for the same product. In this case, consumers may switch between the products because each product has a particular attribute of higher quality. When the firm adopts the commonality strategy, the common attribute will be provided with the same quality. Consequently, the product with a higher-quality custom attribute becomes a dominating product, enhancing product differentiation and making it less attractive for consumers to switch to the product targeted for the other segment.

When the cost saving is sufficiently high, i.e.,

$$\frac{r_1(w_{2k} - w_{1k})}{w_{2k} - r_1 w_{1k}} < \alpha_k < 1 - \frac{c_t w_{2k}(w_{2k} - w_{1k})}{c_k w_{2t}(w_{1t} - w_{2t})(1 - R_t)},$$

the firm will produce a higher-quality common attribute than the attribute in either products without commonality, i.e.,

$$q_k^C = \frac{w_{2k}}{2c_k(1-\alpha_k)} > q_{2k}^{NC} = \frac{w_{2k}(1-R_k)}{2c_k} > q_{1k}^{NC} = \frac{w_{1k}}{2c_k}.$$

Because this common attribute is favored more by the segment whose participation constraint is binding in equilibrium, the common attribute's higher level of quality will increase consumers' willingness to pay, thus relaxing the participation constraint. Consequently, the firm can charge a higher price without worrying about a lack of participation by that segment. The higher price for the product targeting the participation constraint binding segment, in turn, lowers the incentive of the other segment from switching to the product targeting this segment, thus relieving cannibalization among the products.

To illustrate the above argument mathematically, we can calculate the utility change ($w_{1k}(q_k^C - q_{2k}^{NC}) = w_{1k}\{(w_{2k} - w_{2k}(1-R_k)(1-\alpha_k))/(2c_k(1-\alpha_k))\}$) for consumers whose self-selection constraint is binding in equilibrium if they choose to buy the product targeting the participation constraint binding segment, and we compare it with the change in price ($w_{2k}(q_k^C - q_{2k}^{NC}) = w_{2k}\{(w_{2k} - w_{2k}(1-R_k)(1-\alpha_k))/(2c_k(1-\alpha_k))\}$) of that product. From this comparison, since $w_{1k} < w_{2k}$, we get $w_{1k}(q_k^C - q_{2k}^{NC}) < w_{2k}(q_k^C - q_{2k}^{NC})$, which means that the increase in the utility for those consumers is less than the increase of product price. Consequently, this allows the firm to increase the price of the product targeting consumers whose self-selection constraint is binding by $(w_{2k} - w_{1k})\{(w_{2k} - w_{2k}(1-R_k)(1-\alpha_k))/(2c_k(1-\alpha_k))\}$, which results in reduced surpluses to the segment with the self-selection binding constraint, $\Delta S < 0$, and a revenue increase of $r_1(w_{2k} - w_{1k})\{(w_{2k} - w_{2k}(1-R_k)(1-\alpha_k))/(2c_k(1-\alpha_k))\}$.

Consider Apple's iPod product line, where style and storage are the two primary attributes. There are two products: the iPod Nano is targeted toward style-conscious customers who primarily care about size, and the iPod Classic is targeted toward heavy users for whom storage space is more important. In this example, when Apple adopts a high level of commonality, i.e., storage space with iCloud service, in both the iPod Nano and the iPod Classic, common intuition might suggest that it may blur the distinction between the two products and intensify product cannibalization. However, our result in Proposition 2 indicates that the improved storage space as a result of iCloud for both iPod Nano and iPod Classic improves the willingness to pay of the consumers who highly value storage space. Consequently, Apple can charge a higher price for iPod Classic, and this makes the style-conscious consumers less likely to switch to iPod Classic. As a result, the cannibalization between iPod Nano and iPod Classic is relieved, and Apple can increase the price of the iPod Nano, too.

The message in Proposition 2 has important implications for marketing managers when they design the product line. They should carefully examine the consumer preference structure in their particular markets. If it is similar to a dominating structure, marketing managers should be cautious in adopting product commonality, which may intensify the cannibalization among products in the product lines. However, if the consumer preference structure is similar to a nondominating structure, marketing managers should be less concerned with the commonality strategy because commonality can actually relieve cannibalization in the product line. These insights are important for managers in industries such as automobile, electronics, food, banking, and travel, where commonality can provide substantial cost savings.

As Proposition 2 shows, product commonality relieves cannibalization in the product line only when the cost saving is sufficiently high:

$$\frac{r_1(w_{2k}-w_{1k})}{w_{2k}-r_1 w_{1k}} < \alpha_k < 1 - \frac{c_t w_{2k}(w_{2k}-w_{1k})}{c_k w_{2t}(w_{1t}-w_{2t})(1-R_t)}.$$

When the cost saving is low,

$$\frac{r_1(w_{2k}-w_{1k})^2}{r_1(w_{2k}-w_{1k})^2+r_2 w_{2k}^2} < \alpha_k < \frac{r_1(w_{2k}-w_{1k})}{w_{2k}-r_1 w_{1k}},$$

the firm will produce a common attribute of lower quality than that for the product targeting the participation constraint binding segment without commonality ($q_{2k}^{NC} = w_{2k}(1-R_k)/2c_k > q_k^C = w_{2k}/(2c_k(1-\alpha_k)) > q_{1k}^{NC} = w_{1k}/2c_k$). In this case, the firm has to lower its price to satisfy the participation constraint of these consumers so that they remain in the market. The lowered price may induce consumers from the other segment to switch their product preference, causing product cannibalization ($\Delta S > 0$). To combat this, the firm has to reduce the price of the product targeting the segment whose self-selection constraint is binding in equilibrium. Thus, Proposition 2 shows that the cost saving stemming from product commonality is crucial in determining whether cannibalization is intensified or relieved. This also alerts marketing researchers who usually ignore supply-side factors such as design, manufacturing, and logistics costs when studying marketing problems.

We now consider the case where the segment whose self-selection constraint is binding favors the common attribute more ($w_{1k} > w_{2k}$), and we compare the firm's profits with and without product commonality. The results are illustrated in the bottom half of Figure 1 and are summarized as follows.

Proposition 3. *When the firm optimally adopts product commonality* ($\pi^C > \pi^{NC}$) *and the common attribute is favored more by the first segment* (*the segment whose self-selection constraint is binding in equilibrium*) ($w_{1k} > w_{2k}$), *cannibalization is always intensified* ($\Delta S > 0$) *regardless of preference structure.*

Proposition 3 contrasts with Proposition 2 and shows that product commonality relieves product cannibalization only when the consumer preference structure is nondominating and the common attribute is the one favored more by the segment whose participation constraint is binding in equilibrium. If the common attribute is favored more by the other segment regardless of preference structure as Proposition 3 shows, commonality cannot relieve product cannibalization. If the common attribute is the one favored more by the segment whose self-selection constraint is binding in equilibrium, the improvement of quality on that attribute in the product targeting the participation constraint binding segment will make that product more attractive for consumers whose self-selection constraint is binding in equilibrium, thus exacerbating cannibalization. Consequently, the firm has to reduce the price of the product targeting the segment whose self-selection constraint is binding in equilibrium. Thus, Proposition 3 shows that whether product commonality can relieve product cannibalization depends on which type of attributes become common and that marketing managers need to examine their product attributes and consumer segment characteristics in the markets.

It is important to note that there are some disadvantages in introducing product commonality even in a market with a nondominating consumer preference structure. With product commonality, the firm will lose the opportunity to design different quality levels of the common attribute for consumers who value the attribute differently. Therefore, the saving on manufacturing cost is a must for a firm to benefit from the commonality strategy, and the benefit comes from the possibility of providing a much higher level of quality. What Propositions 2 and 3 also show is that even with the diminished capability of differentiating consumers, the commonality strategy can be profitable. It improves the firm's revenue through reducing cannibalization, provided the market consists of segments with a nondominant preference structure. In a dominating consumer preference structure, the adaption of commonality intensifies cannibalization, and the benefit from product commonality comes only from the manufacturing cost savings as a result of product commonality (Desai et al. 2001, Heese and Swaminathan 2006). Proposition 1 shows that it is more likely for a firm to benefit from product commonality in markets where consumers show a nondominating preference structure.[4] The threshold

[4] In Proposition 1, suppose the threshold value for cost savings is α_k^{ND} when the preference structure is nondominating, i.e., $w_{1t} > w_{2t}$ and $w_{1k}^{ND} < w_{2k}^{ND}$. Let α_k^D denote the threshold value when the preference structure is dominating, i.e., $w_{1t} > w_{2t}$ and $w_{1k}^D > w_{2k}^D$.

value for the cost savings parameter is lower and hence easier to satisfy under the nondominating preference structure. This gives rise to an opportunity, previously thought unavailable in the product commonality literature (Kim and Chhajed 2000, Desai et al. 2001, Krishnan and Gupta 2001, Heese and Swaminathan 2006), for firms to profit from redesigning the product line with commonality.

In addition to the contribution to the product commonality literature, the results in Propositions 2 and 3 also contribute to the literature on product customization and targeted marketing (Shaffer and Zhang 1995, 2002; Chen et al. 2001; Villas-Boas 2004b; Liu and Zhang 2006). We show that providing standardized product attributes through commonality can also provide demand-side benefits to the firm, just as in the case of offering different product attributes through product customization. The mechanism provided in this paper on the possible beneficial effects of product standardization is novel, and it contributes as a new mechanism to the marketing literature on product customization and targeted marketing.

In the model analysis, we have focused on the most interesting case of interior solutions where the self-selection constraint is binding for the first segment and the participation constraint is always binding for the second segment in equilibrium regardless of whether the firm adopts product commonality. We now briefly discuss other cases. First, when the participation constraints for both segments are binding in equilibrium with or without product commonality, it is straightforward to see that optimality of product commonality does not alleviate product cannibalization because consumer surplus is always 0 with or without commonality ($\Delta S = 0$). Second, when the participation constraint is binding for the first segment with product commonality, but not without product commonality, whereas the participation constraint is always binding for the second segment in equilibrium, the result is also straightforward: product commonality always relieves cannibalization because consumers receive zero surplus with product commonality but positive surplus without product commonality ($\Delta S < 0$). Finally, when the participation constraint is not binding for the first segment with product commonality but is binding without product commonality, whereas the participation constraint is always binding for the second segment in equilibrium, product commonality always intensifies cannibalization ($\Delta S > 0$).

To compare these two cases, we make the valuation for attribute k symmetric by setting $w_{1k}^{D} = w_{2k}^{ND}$ and $w_{2k}^{D} = w_{1k}^{ND}$. Then it is easy to see that the threshold value of the cost saving parameter for the optimality of commonality strategy is smaller under nondominating preference structure, i.e., $\alpha_k^{ND} < \alpha_k^{D}$. Note that we do not consider the case of $w_{1t} < w_{2t}$ because the comparison between dominating and nondominating preference structures would be infeasible with the second segment being the dominating segment (and $w_{1k} < w_{2k}$) for which the current interior solutions are infeasible.

4. Conclusion

In many markets, consumers in different consumer segments may have diverse preferences for different product attributes. Even for vertical attributes such as quality, although all consumers prefer high quality to low quality, the magnitude of preference can be different for different consumers. More important, consumers who highly value a particular attribute may not be the same consumers who highly value another attribute. Diverse consumer preferences on different attributes pose significant challenges for marketing managers on product line designs in many industries such as automobile and electronics. However, in these industries, advances in manufacturing technology often allow firms to use common components for their product lines.

It was widely believed among marketing and operations scholars that firms adopt a commonality strategy for the sake of cost savings at the expense of product differentiability. This suggests that firms are more likely to choose a common attribute that exhibits a large potential cost savings and that the characteristics of the consumer market are relatively less important. This perception prevails without a complete understanding of the role of the preference structure among consumers in different markets. Our analysis of commonality for consumer segments with nondominating consumer preference structure shows that the commonality strategy exhibits much more diverse effects. Thus, a careful examination of the consumer preference structure in a particular market is necessary for marketing managers before adopting the commonality strategy.

One of the most interesting findings of this paper is that when consumer preference is nondominating, commonality and its associated cost savings can help firms design better product lines with common components and attributes, and thus improve their profits. Our findings can be very practical for marketing managers. Consider the example of Acura and Accord. With these two models, style and design would be considered the custom attribute, and fuel economy would be considered the common attribute. Suppose that the segment that prefers design and style more is the segment more likely to switch. Our model demonstrates that the commonality of fuel economy between Acura and Accord (such as the fuel efficiency of hybrid technology) might help the firm to better differentiate between consumers and improve profits. As a matter of fact, Honda will introduce both Acura Hybrid and Accord Hybrid models in 2013; this development reflects the increasing popularity of hybrid technology employed in the automobile industry. The findings in this paper can also provide possible explanations for other cases such as Apple's efforts to provide iCloud services to its customers of different products; banks' endeavor to provide convenient online banking services to their customers; food manufacturers improving the taste of products targeting both taste-conscious and health-conscious consumers; and manufacturers in many industries standardizing materials, ingredients, or parts in their product lines. This paper further highlights the sentiments expressed by Desai et al. (2001, p. 38), "At a very broad strategic level, our results show that close coordination among design, manufacturing, and marketing departments is needed to fully evaluate the profitability of common components and make sound decisions about configuration, component qualities, and product prices."

We acknowledge some caveats in this paper regarding the model and results. To make the results more tractable and explicit, we use a specific utility and cost function to illustrate the new insights on product commonality. It is not clear what characteristics of the utility and cost functions are necessary to show our results. Models with more general functions of consumer utilities or costs can be developed to study the issues of product commonality, although those models can be more technically challenging. In addition, we use a two-segment model, and consumers in each segment are homogeneous. This may be far from realistic because consumers even in the same segment can be heterogeneous on some dimensions. For instance, even for consumers who all use iPod Classic, the importance of storage space can differ. Furthermore, the cost savings of product commonality can be driven by either economy of scale or fixed production cost reduction. In the first case, the marginal cost reduction can depend on the quantity of products produced; in the second case, the fixed cost reduction does not depend on product quantity. Further research is needed in all those directions to confirm the results in the current paper.

Acknowledgments
The authors thank the editor, associate editor, and two anonymous referees for constructive comments and suggestions that significantly improved this paper. Special thanks to the editor for his efforts. The usual disclaimer applies. K. Kim's work was supported by the National Research Foundation of Korea Grant funded by the Korean Government [NRF-2010-330-B00107].

Appendix

Solution for CPD
In problem CPD, the firm will extract all surpluses from at least one segment in equilibrium. Since two segments are symmetric, we denote $P_1 = U_{11} - S$ and $P_2 = U_{22}$, where $U_{11} = w_{1t}q_{1t} + w_{1k}q_k$, $S = (w_{1t} - w_{2t})q_{2t} + (w_{1k} - w_{2k})q_k \geq 0$ and $U_{22} = w_{2t}q_{2t} + w_{2k}q_k$. Constraints (1) and (4) are binding in problem (CPD), so that the problem reduces to

$$\max_{q_{1t},\, q_{2t},\, q_k} \; \{r_1\{w_{1t}q_{1t} - (w_{1t} - w_{2t})q_{2t} - c_t q_{1t}^2\} + r_2\{w_{2t}q_{2t} - c_t q_{2t}^2\} + \{w_{2k}q_k - c_k(1-\alpha_k)q_k^2\}\}$$

$$\text{subject to} \quad (w_{1t} - w_{2t})q_{2t} + (w_{1k} - w_{2k})q_k \geq 0, \tag{5}$$

$$(w_{1t} - w_{2t})(q_{1t} - q_{2t}) \geq 0, \tag{6}$$

$$q_{1t} \geq 0,\; q_{2t} \geq 0,\; q_k \geq 0.$$

Because the above problem has a concave objective function with linear constraints, the first-order necessary conditions are also sufficient to find the global maximum. We form a Lagrangian relaxation with multiplier λ_1 for the first constraint (5), μ_{1t} for q_{1t}, μ_{2t} for q_{2t}, and μ_k for q_k. The Lagrangian relaxation is as follows:

$$\begin{aligned} W(\lambda_1, \mu_{1t}, \mu_{2t}, \mu_k) &= \max_{q_{1t},\, q_{2t},\, q_k} \{r_1\{w_{1t}q_{1t} - d_t q_{2t} - c_t q_{1t}^2\} + r_2\{w_{2t}q_{2t} - c_t q_{2t}^2\} + \{w_{2k}q_k - c_k(1-\alpha_k)q_k^2\}\} \\ &\quad + \lambda_1\{(w_{1t} - w_{2t})q_{2t} + (w_{1k} - w_{2k})q_k\} \\ &\quad + \mu_{1t}q_{1t} + \mu_{2t}q_{2t} + \mu_k q_k, \end{aligned}$$

where $d_j = (w_{1j} - w_{2j})$, $j = t, k$.

The Lagrangian dual is

$$\min_{\lambda_1,\, \mu_{1t},\, \mu_{2t},\, \mu_k} W(\lambda_1, \mu_{1t}, \mu_{2t}, \mu_k),$$

and necessary conditions are

$$\frac{\partial W}{\partial q_{1t}} = 0, \quad \frac{\partial W}{\partial q_{2t}} = 0, \quad \frac{\partial W}{\partial q_k} = 0,$$

$$\lambda_1\{(w_{1t} - w_{2t})q_{2t} + (w_{1k} - w_{2k})q_k\} = 0,$$

$$\mu_{1t}q_{1t} = 0, \quad \mu_{2t}q_{2t} = 0, \quad \mu_k q_k = 0, \quad \lambda_1 \geq 0, \quad \mu_{1t} \geq 0,$$

$$\mu_{2t} \geq 0, \quad \mu_k \geq 0.$$

Taking derivatives of W with respect to q_{1t}, q_{2t}, and q_k, we obtain

$$q_{1t} = \frac{w_{1t}}{2c_t} + \frac{\mu_{1t}}{2r_1c_t}, \quad q_{2t} = \frac{r_2w_{2t} - r_1d_t - \lambda_1w_{2t} + \mu_{2t}}{2r_2c_t},$$

$$q_k = \frac{w_{2k} + \mu_k + \lambda_1 d_k}{2c_k(1-\alpha_k)}.$$

We focus on the interior solutions when $\lambda_1 = 0$. The optimal product design becomes

$$q_{1t} = \frac{w_{1t}}{2c_t} + \frac{\mu_{1t}}{2r_1c_t}, \quad q_{2t} = \frac{w_{2t}(1-R_t)}{2c_t} + \frac{\mu_{2t}}{2r_2c_t},$$

$$q_k = \frac{w_{2k}}{2c_k(1-\alpha_k)} + \frac{\mu_k}{2c_k(1-\alpha_k)},$$

where $R_t = r_1(w_{1t} - w_{2t})/r_2w_{2t}$.

We now use the complementary slackness conditions for q_{1t}, q_{2t}, and q_k:

- $q_{1t} = w_{1t}/(2c_t) + \mu_{1t}/(2r_1 c_t) = 0$ is impossible with $\mu_{1t} > 0$; thus we must have $\mu_{1t} = 0$ and $q_{1t}^C = w_{1t}/(2c_t)$.
- If $R_t < 1$, $q_{2t} = w_{2t}(1-R_t)/(2c_t) + \mu_{2t}/(2r_2 c_t) = 0$ and $\mu_{2t} > 0$ are in contradiction, so we must have $\mu_{2t} = 0$ and $q_{2t}^C = w_{2t}(1-R_t)/(2c_t) > 0$.
- If $R_t \geq 1$, $q_{2t} = w_{2t}(1-R_t)/(2c_t) + \mu_{2t}/(2r_2 c_t) > 0$ and $\mu_{2t} = 0$ are in contradiction, so we must have $\mu_{2t} > 0$ and $q_{2t}^C = 0$.
- $q_k = w_{2k}/(2c_k(1-\alpha_k)) + \mu_k/(2c_k(1-\alpha_k)) = 0$ is impossible with $\mu_k > 0$; thus we must have $\mu_k = 0$ and $q_k^C = w_{2k}/(2c_k(1-\alpha_k))$.

From the condition of this case, $S = (w_{1t} - w_{2t})q_{2t} + (w_{1k} - w_{2k})q_k > 0$; if $w_{1t} > w_{2t}$ and $R_t \geq 1$ so that $q_{2t} = 0$, then there is no feasible solution. Therefore, the optimal product design for the current case is as follows:

$$q_{1t}^C = \frac{w_{1t}}{2c_t}, \quad q_{2t}^C = \frac{w_{2t}(1-R_t)}{2c_t} \quad \text{if } R_t < 1, \quad q_k^C = \frac{w_{2k}}{2c_k(1-\alpha_k)},$$

$$\pi^C = \frac{r_1 w_{1t}^2 + r_2 w_{2t}^2 (1-R_t)^2}{4c_t} + \frac{w_{2k}^2}{4c_k(1-\alpha_k)},$$

$$\text{where } R_t = r_1(w_{1t} - w_{2t})/r_2 w_{2t}.$$

The above solutions are valid as long as constraints (5) and (6) are satisfied. First, consider (5). Substituting for q_{2t}^C and q_k^C and using some algebraic manipulations, we get

$$\frac{r_1}{r_2} \leq \frac{c_k(1-\alpha_k)w_{2t}(w_{1t} - w_{2t}) + c_t w_{2k}(w_{1k} - w_{2k})}{c_k(1-\alpha_k)(w_{1t} - w_{2t})^2} \quad \text{or}$$

$$\alpha_k \leq 1 - \frac{c_t w_{2k}(w_{2k} - w_{1k})}{c_k w_{2t}(w_{1t} - w_{2t})(1-R_t)} \quad \text{if } w_{1t} > w_{2t},$$

$$\alpha_k \geq 1 - \frac{c_t w_{2k}(w_{2k} - w_{1k})}{c_k w_{2t}(w_{1t} - w_{2t})(1-R_t)} \quad \text{otherwise.}$$

Furthermore, (6) always holds for the obtained solutions. To see this,

$$(w_{1t} - w_{2t})(q_{1t}^C - q_{2t}^C) = \frac{(w_{1t} - w_{2t})^2(1 + r_1/r_2)}{2c_t} \geq 0.$$

On the other hand, under the noncommonality strategy, the optimal interior solution is as follows (see Kim and Chhajed 2002):

$$q_{1t}^{NC} = \frac{w_{1t}}{2c_t}, \quad q_{2t}^{NC} = \frac{w_{2t}(1-R_t)}{2c_t} \quad \text{if } R_t < 1,$$

$$q_{1k}^{NC} = \frac{w_{1k}}{2c_k}, \quad q_{2k}^{NC} = \frac{w_{2k}(1-R_k)}{2c_k} \quad \text{if } R_k < 1,$$

$$\pi^{NC} = \frac{r_1 w_{1t}^2 + r_2 w_{2t}^2(1-R_t)^2}{4c_t} + \frac{r_1 w_{1k}^2 + r_2 w_{2k}^2(1-R_k)^2}{4c_k},$$

$$\text{where } R_k = r_1(w_{1k} - w_{2k})/r_2 w_{2k}.$$

The necessary condition is given by

$$\frac{r_1}{r_2} \leq \frac{c_k w_{2t}(w_{1t} - w_{2t}) + c_t w_{2k}(w_{1k} - w_{2k})}{c_k(w_{1t} - w_{2t})^2 + c_t(w_{1k} - w_{2k})^2}.$$

Therefore, when making a comparison of the optimal interior solutions under commonality and noncommonality strategies, the following condition should hold:

$$\frac{r_1}{r_2} \leq \min\left\{ \frac{c_k w_{2t}(w_{1t} - w_{2t}) + c_t w_{2k}(w_{1k} - w_{2k})}{c_k(w_{1t} - w_{2t})^2 + c_t(w_{1k} - w_{2k})^2}, \frac{c_k(1-\alpha_k)w_{2t}(w_{1t} - w_{2t}) + c_t w_{2k}(w_{1k} - w_{2k})}{c_k(1-\alpha_k)(w_{1t} - w_{2t})^2} \right\}.$$

Proof of Proposition 1

Profits from π^C and π^{NC} can be compared as follows:

$$\pi^C - \pi^{NC} \Leftrightarrow \frac{w_{2k}^2}{4c_k(1-\alpha_k)} - \frac{r_1 w_{1k}^2 + r_2 w_{2k}^2(1-R_k)^2}{4c_k}$$

$$\Leftrightarrow \frac{r_1 w_{1k}^2 + r_2 w_{2k}^2(1-R_k)^2}{4c_k(1-\alpha_k)} \left\{ \alpha_k - \frac{r_1(w_{2k} - w_{1k})^2}{r_1(w_{2k} - w_{1k})^2 + r_2 w_{2k}^2} \right\}.$$

Thus,

$$\pi^C > \pi^{NC} \quad \text{if } \alpha_k > \frac{r_1(w_{2k} - w_{1k})^2}{r_1(w_{2k} - w_{1k})^2 + r_2 w_{2k}^2}. \quad \text{Q.E.D.}$$

Proof of Proposition 2

Note first that if the commonality strategy intensifies the cannibalization, then the feasibility/optimality condition for π^{NC} is tighter than the one for π^C. Note also that $\pi^C > \pi^{NC}$ if $\alpha_k > (r_1(w_{2k} - w_{1k})^2)/(r_1(w_{2k} - w_{1k})^2 + r_2 w_{2k}^2)$. For $w_{1k} < w_{2k}$, if $\alpha_k < (r_1(w_{2k} - w_{1k}))/(w_{2k} - r_1 w_{1k})$, then the commonality strategy intensifies the cannibalization, $\Delta S = (w_{1k} - w_{2k})(q_k^C - q_{2k}^{NC}) > 0$, since

$$q_k^C = \frac{w_{2k}}{2c_k(1-\alpha_k)} < q_{2k}^{NC} = \frac{w_{2k}(1-R_k)}{2c_k} \Leftrightarrow \alpha_k < \frac{r_1(w_{2k} - w_{1k})}{w_{2k} - r_1 w_{1k}}.$$

Since

$$\frac{r_1(w_{2k} - w_{1k})^2}{r_1(w_{2k} - w_{1k})^2 + r_2 w_{2k}^2} < \frac{r_1(w_{2k} - w_{1k})}{w_{2k} - r_1 w_{1k}} \quad \text{for } w_{1k} < w_{2k},$$

when

$$\frac{r_1(w_{2k} - w_{1k})^2}{r_1(w_{2k} - w_{1k})^2 + r_2 w_{2k}^2} < \alpha_k < \frac{r_1(w_{2k} - w_{1k})}{w_{2k} - r_1 w_{1k}},$$

the commonality strategy intensifies the cannibalization, but it is optimal to implement the commonality strategy.

On the other hand, when $\alpha_k > (r_1(w_{2k} - w_{1k}))/(w_{2k} - r_1 w_{1k})$, the commonality strategy relieves the cannibalization problem ($\Delta S < 0$), but in this case, the feasibility/optimality condition for π^C,

$$\alpha_k < 1 - \frac{c_t w_{2k}(w_{2k} - w_{1k})}{c_k w_{2t}(w_{1t} - w_{2t})(1-R_t)} \quad \text{for } w_{1t} > w_{2t},$$

is tighter than the one for π^{NC} so that it should hold to make a proper profit comparison between the two strategies. Thus, for $w_{1t} > w_{2t}$ and $w_{1k} < w_{2k}$, when

$$\frac{r_1(w_{2k} - w_{1k})}{w_{2k} - r_1 w_{1k}} < \alpha_k \leq 1 - \frac{c_t w_{2k}(w_{2k} - w_{1k})}{c_k w_{2t}(w_{1t} - w_{2t})(1-R_t)},$$

the commonality strategy relieves the cannibalization problem and the firm optimally adopts commonality. Q.E.D.

Proof of Proposition 3

Note that in the proof of Proposition 3, it does not matter whether $w_{1t} > w_{2t}$ or $w_{1t} < w_{2t}$. Note also that $\pi^C > \pi^{NC}$ if $\alpha_k > (r_1(w_{2k} - w_{1k})^2)/(r_1(w_{2k} - w_{1k})^2 + r_2 w_{2k}^2)$. For $w_{1k} > w_{2k}$,

$$q_k^C = \frac{w_{2k}}{2c_k(1-\alpha_k)} > q_{2k}^{NC} = \frac{w_{2k}(1-R_k)}{2c_k}$$

so that $\Delta S = (w_{1k} - w_{2k})(q_k^C - q_{2k}^{NC}) > 0$, and the commonality strategy intensifies the cannibalization. In this case, the feasibility/optimality condition for π^{NC} is tighter than the one for π^C so that whenever π^{NC} is implementable, π^C is also implementable. Thus, when $w_{1k} > w_{2k}$ and

$$\alpha_k > \frac{r_1(w_{2k} - w_{1k})^2}{r_1(w_{2k} - w_{1k})^2 + r_2 w_{2k}^2},$$

the commonality strategy intensifies the cannibalization, but the firm optimally adopts commonality. Q.E.D.

References

Aaker DA (1996) *Building Strong Brands* (Free Press, New York).

Calcott P, Walls M (2000) Can downstream waste disposal policies encourage upstream "design for environment"? *Amer. Econom. Rev.* 90(2):233–237.

Calcott P, Walls M (2005) Waste, recycling, and "design for environment": Roles for markets and policy instruments. *Resource Energy Econom.* 27(4):287–305.

Chen Y, Narasimhan C, Zhang ZJ (2001) Individual marketing with imperfect targetability. *Marketing Sci.* 20(1):23–41.

Desai PS (2001) Quality segmentation in spatial markets: When does cannibalization affect product line design? *Marketing Sci.* 20(3):265–283.

Desai P, Kekre S, Radhakrishnan S, Srinivasan K (2001) Product differentiation and commonality in design: Balancing revenue and cost drivers. *Management Sci.* 47(1):37–51.

Fixson SK (2007) Modularity and commonality research: Past developments and future opportunities. *Concurrent Engrg.* 15(2):85–111.

Gerchak Y, Magazine MJ, Gamble AB (1988) Component commonality with service level requirements. *Management Sci.* 34(6):753–760.

Heese HS, Swaminathan JM (2006) Product line design with component commonality and cost-reduction effort. *Manufacturing Service Oper. Management* 8(2):206–219.

Kim K, Chhajed D (2000) Commonality in product design: Cost saving, valuation change, and cannibalization. *Eur. J. Oper. Res.* 125:602–621.

Kotler P (2002) *Marketing Management* (Prentice-Hall, Englewood Cliffs, NJ).

Krishnan V, Gupta S (2001) Appropriateness and impact of platform-based product development. *Management Sci.* 47(1):52–68.

Lancaster K (1979) *Variety, Equity, and Efficiency: Product Variety in an Industrial Society* (Columbia University Press, New York).

Lee HL, Billington C (1994) Designing products and processes for postponement. Dasu S, Eastman C, eds. *Management of Design: Engineering and Management Perspectives* (Kluwer Academic Publishers, Boston), 105–122.

Liu Y, Zhang ZJ (2006) The benefits of personalized pricing in a channel. *Marketing Sci.* 25(1):97–105.

Meyer MH, Lehnerd AP (1997) *The Power of Product Platforms* (Free Press, New York).

Moorthy KS (1984) Market segmentation, self-selection, and product line design. *Marketing Sci.* **3**(4):288–307.

Moorthy KS, Png IPL (1992) Market segmentation, cannibalization, and the timing of product introductions. *Management Sci.* 38(3):345–359.

Muffatto M (1999) Platform strategies in international new product development. *Internat. J. Oper. Production Management* 19(5):449–459.

Mussa M, Rosen S (1978) Monopoly and product quality. *J. Econom. Theory* 18(2):301–317.

Quelch JA, Kenny D (1994) Extend profits, not product lines. *Harvard Bus. Rev.* 72(5):153–162.

Salvador F (2007) Towards a product system modularity construct: Literature review and reconceptualization. *IEEE Trans. Engrg. Management* 54(2):219–240.

Sanderson SW, Uzumeri V (1997) *Managing Product Families* (Irwin, Homewood, IL).

Shaffer G, Zhang ZJ (1995) Competitive coupon targeting. *Marketing Sci.* 14(4):395–416.

Shaffer G, Zhang ZJ (2002) Competitive one-to-one promotions. *Management Sci.* 48(9):1143–1160.

Smith PG, Reinertsen DG (1991) *Developing Products in Half the Time: New Rules, New Tools* (Van Nostrand Reinhold, New York).

Villas-Boas JM (2004a) Communication strategies and product line design. *Marketing Sci.* 23(3):304–316.

Villas-Boas JM (2004b) Price cycles in markets with customer recognition, *RAND J. Econom.* 35(3):486–501.