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Product design strategies in a manufacturer–retailer distribution channel

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ABSTRACT

Product design decision has significant impacts on firm's competitive edge. In a distribution channel, product design strategy of a manufacturer depends not only on its own decisions, but also on the behaviors of its upstream and downstream partners along the channel. This paper investigates the optimal product design strategy of a manufacturer in a two-stage supply chain that consists of an upstream manufacturer and a downstream retailer. Customers are classified into two groups (i.e., two market segments) according to their difference on quality valuations. For each of the two potential market segments, the manufacturer needs to decide if it is beneficial to design a product with appropriate quality level to meet the demand of customers in the market segment. The retailer procures the product from the manufacturer, and then sells to customers at a retail price. By considering the interactions between the manufacturer and the retailer, this paper first describes the product design problem as a manufacturer-dominant Stackelberg game, and presents the optimal product design strategy for the manufacturer. To improve the performance of the supply chain, the revenue-sharing contract is then introduced into the product design problem. It is found that the revenue-sharing contract can perfectly coordinate the distribution channel in the product design problem. Numerical experiments illustrate the impacts of customer characteristics on the optimal product design strategies.

1. Introduction

Manufacturers in many industries depend on intermediate parties to sell their products to customers. For example, frequently purchased consumer products, home appliances, personal computers, and automobiles are usually sold to different market segments through appropriate media [1]. Because different parties along a distribution channel may not share the same interest, the distribution channel is usually a distributed system, and not fully coordinated in product design problem [2]. In the distribution channel, the retailer, rather than the manufacturer, controls the ultimate targeting of the products in the line to the consumers of different market segments, thus product design decisions cannot be made by solely maximizing the profit of the manufacturer.

This paper investigates the product design problem in a distribution channel that consists of an upstream manufacturer and a downstream retailer. According to their difference on quality valuations, potential customers are classified into two groups, which are defined as two market segments. In one market segment, to which we refer high-end segment, customers are very sensitive to product quality; in the other market segment, to which we refer low-end segment, customers are not so sensitive to product quality. We assume that utility of customer from buying a product is a function of quality level and retail price of the product. Customers in each market segment make buying decisions to maximize their utility. To make the market segmentation meaningful, it is required that customers in one market segment will never buy the product designed for the other market segment.

Given the above two market segments, the manufacturer has four possible product design strategies: design two products respectively for the two market segments, just design one product for one of the two market segments, or design no product. With specified product design strategy and quality levels of the products, the manufacturer sells the designed product(s) to the retailer, and then the retailer sells the product to the market. Since the retailer usually makes retailing decisions (e.g., sale price) to maximize its own profit, production conditions and characteristics of market demand are necessary but not sufficient in making the optimal product design decision. In other words, interactions between the manufacturer and the retailer, and between the retailer and customers, are important in determining the optimal product design strategy in a distribution channel.

Product design problem has been investigated by many researchers. Most of the previous research deals with this problem solely from the perspective of the manufacturer, e.g., design for quality [3–5], design for manufacturability [6–11], or design for manufacturing flexibility [12,13]. Little attention has been invested in the product design problem in a distribution channel. Recently, some researchers have addressed this problem. In a two-stage supply chain that consists of one manufacturer and

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one retailer, Villas-Boas [1] investigates the product line design problem when there are two market segments with constraints of customer valuation. However, this paper assumes that retail price is totally decided by the retailer, thus interaction between the manufacturer and retailer is essentially ignored. Xu [2] studies a joint pricing and product quality decision problem in a distribution channel, in which a manufacturer sells a product through a retailer. When the manufacturer and the retailer do not cooperate on the joint decision-making problem, the paper presents the conditions when a direct-sell channel or an indirect-sell channel is optimal. Given the specific channel structure, the paper does not address the problem of improving the performance of the channel.

Considering the interactions between decisions on quality levels and retail prices, this paper first investigates the optimal product design strategy when the retailer and the manufacturer do not cooperate, then applies the revenue-sharing contract to the product design problem to coordinate the distribution channel [14,15]. Revenue-sharing is a widely applied coordinating mechanism to motivate supply chain members to cooperate on order policy selection [16], promotion [17–20], or business risk reduction [21–23]. In this paper, we applied it to product design problem. Compared with the previous researches, this paper contributes the related research on two aspects: (1) we investigate the product design problem with interactions between the manufacturer and the retailer, and find the optimal strategies for the manufacturer in a distribution channel under various market conditions; (2) we apply the revenue-sharing contract to the product design problem in a distribution channel, and find that it can perfectly coordinate the supply chain.

The remainder of this paper is structured as follows. In Section 2, we describe the product design problem. In Section 3, performance of non-cooperative product design decision is analyzed. In Section 4, we apply the revenue-sharing contract to the product design problem. Numerical illustration is provided in Section 5, and the paper ends with some conclusions in Section 6.

2. Problem description

We consider a two-stage supply chain consisting of an upstream manufacturer and a downstream retailer. The manufacturer designs and produces two products with different quality levels for two market segments, and then sells the products to the retailer; the retailer procures the products from the manufacturer, and then sells to two market segments with different retail prices. We assume that utility of customer from buying a product is a function of quality level and retail price of the product, and that a customer makes buying decision to maximize his/her utility.

Considering the difference between customers in the two market segments, the manufacturer has the options of designing two products for the corresponding two market segments, just designing one product catering to only one of the two market segments (and not serves the other), or designing no product. Given the characteristics of customers in the two market segments, the product design decisions in this distribution channel depend, not only on the benefit of the manufacturer, but also on the benefit of the retailer.

Denote the indexes of high- and low-end market segments by H and L, respectively. Customers in segment H have a higher marginal valuation v_H per unit quality than that of the customers in segment $L(v_L)$ with $v_H \geq v_L > 0$. Since the manufacturer has the option to design two products for segments H and L, we denote the two products also as products H and L, with high quality level q_H and low quality level $q_L(q_H \geq q_L \geq 0)$, respectively. Manufacturing cost of a product with quality q_j is assumed to be $c_j = k_j q_j^2$ $(k_j > 0, j = H, L)$, where k_j is a scalar cost coefficient that recognizes differences in cost of producing unit quality across products. So we have $k_H > k_L$ [24].

Suppose that the retailer sells product $j(j = H, L)$ at prices p_j. Then market demand in segment i, $D_i(i = H, L)$, can be described as a linear function of p_j, i.e., $D_i = M_i - a_i p_j$ $(M_i > 0,\ 0 < a_H < a_L,\ M_i/a_i \geq p_j \geq 0,\ i = j = H, L)$ [25,26].

The utility that a consumer in market segment $i(i = H, L)$ derives from buying product $j(j = H, L)$, U_{ij}, is given by

$$U_{ij} = v_i q_j - p_j \quad (i, j = H, L). \tag{1}$$

The utility function defined in Eq. (1) emphasizes the risk of cannibalization when self-selecting customers with a high willingness to pay for quality are attracted to cheaper products of lower quality [27]. The first term of the utility function represents the consumer's maximum willingness to pay or the reservation price. The price should have to be lower than the reservation price to induce the consumer to buy the product. This is a common way of representing markets characterized by quality differentiation (see, for example, [27–30]). Note that the utility function is defined based on consumer self-selection. The manufacturer and the retailer, in recognition of such self-selection opportunities, have to choose the product design strategy and retail prices so that consumers are willing to buy products aimed at their own segments.

The decision of product design made by the manufacturer can be described by the value of $q_j(j = H, L)$. That is, if $q_j = 0$ for $\forall j \in \{H, L\}$, then the manufacturer should not introduce product j into the market because no customer will buy this product (i.e., $U_{ij} \leq 0$ for $i = H, L$). In the product design problem, we assume that the manufacturer and the retailer are risk-neutral (see [31,32] for the discussion of other possible forms of utility function), and make decisions to maximize their own profits. The resulted problem is a non-cooperative scenario of product design.

When the manufacturer sells product j to the retailer at price $w_j(j = H, L)$, profit of the manufacturer obtained through manufacturing products H and L is computed by

$$\begin{aligned}\pi_m &= (w_H - c_H)D_H + (w_L - c_L)D_L \\ &= (w_H - k_H q_H^2)(M_H - a_H p_H) + (w_L - k_L q_L^2)(M_L - a_L p_L).\end{aligned} \tag{2}$$

Similarly, profit of the retailer from selling products H and L is

$$\begin{aligned}\pi_r &= (p_H - w_H)D_H + (p_L - w_L)D_L \\ &= (p_H - w_H)(M_H - a_H p_H) + (p_L - w_L)(M_L - a_L p_L).\end{aligned} \tag{3}$$

As shown in Eqs. (2) and (3), profit of the manufacturer or the retailer depends on the manufacturer's decision on product quality $q_j(j = H, L)$, and the retailer's decision on retail price p_j as well. In other words, to make the optimal decision on product design, the manufacturer should not only consider its own cost structure, but also consider the corresponding pricing decision made by the retailer.

In maximizing π_m and π_r, some basic constraints of customer valuation should be satisfied. To ensure customers in market segment H (or L) have the possibility to buy products H (or L) designed for them, it is nature to require that

$$v_H q_H - p_H \geq 0, \tag{4}$$

$$v_L q_L - p_L \geq 0. \tag{5}$$

Constraints (4) and (5) are termed individual rationality constraints [1,33]. Note that the utility of a customer in segment H (or L) from buying product L (or H) can be positive or negative.

When the manufacturer designs two products, to ensure that customers in each market segment buy the product specifically