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A two-product newsvendor system with a flexible product

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ABSTRACT

In this paper, we investigate the effect of offering a flexible product in a newsvendor system with two products. We show that this flexible selling strategy can help firms effectively pool excess stocks to better match supply with demand and thus enhance profitability. However, offering a flexible product may also bring the potential risk of cannibalizing regular demand. We explore this trade-off by incorporating pricing decision for the flexible product when demand cannibalization exists. Our study shows that even when there is no demand induction effect, offering a flexible product still significantly improves profit. The value of offering a flexible product is highest when prices for specific products are the same, and it increases when the demands for specific products are more negatively correlated, more volatile, and more symmetric. Furthermore, the performance improvement is more salient when products have narrow profit margin or high overage risk.

1. Introduction

Selling flexible products has become more and more popular in business. According to Fay and Xie (2008), a flexible product or probabilistic good "is not a concrete product or service, but an offer involving a probability of getting any one of a set of multiple distinct items". A flexible product typically consists of a set of possible alternatives, known as specific products, which are usually substitutable, and a buyer is later assigned to one of the alternatives depending on the availability of the set of specific products. For example, the international hotel chain, Crowne Plaza, offers a room type called the Crowne Plaza Superior Room, in addition to other specific room types, and states that "when you arrive, we will do our best to meet your room bed type and smoking preferences. These are subject to availability and can not be guaranteed." If customers book this kind of flexible room, the specific room type is revealed only when they check into the hotel. Flexible products have been applied in a number of industries, such as Internet advertising, air cargo, tour operators, multiple property management, and opaque fares (Gallego and Phillips, 2004). Flexible products are also found in retailing. For example, a retailer selling different colors of garments may offer a flexible product that is one of the alternatives.

There are several benefits of offering flexible products in addition to specific products. First, it enables sellers to exploit the benefit of risk pooling. Predicting the hot item in a set of alternatives is usually challenging, making it hard to match supply with demand. By postponing the allocation of products to flexible customers until after the demand realization of specific products, sellers can make the best use of their supplies to meet demand and thus enhance their capacity utilization. This risk pooling effect is built on a special type of customer heterogeneity. In almost all markets with multiple product offerings, customers differ in the strength of their preferences (Fay and Xie, 2008). Some customers have strong preferences for a certain product among the alternatives, and do not make a purchase if their preferred product is not available. This segment of customers are typically less price sensitive. They view flexible products as inferior to specific products, because they can not self-select. Even offering discounts on flexible products does not attract them. Thus, sellers must meet the exact requirements of this segment of customers. Some customers have weak preferences, and are indifferent to alternatives. This group of customers are usually more price sensitive. If flexible products are less expensive, they don't mind giving up the right to self-selection. This heterogeneity in the extent of customer preference provides companies the opportunity to improve profit. In particular, when there is a demand supply imbalance, there may be leftovers of one product and a shortage of another. Offering flexible products allows sellers to resolve this kind of mismatch. In this case, demands for specific products are met first, thereby reducing lost sales; whereas demands for flexible products are met afterward based on the remaining inventory. As mentioned in Fay and Xie (2008), offering flexible products can reduce

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Table 1
The effect of price asymmetry on the decisions and performance gap.

p_a	(Q_a^{nv}, Q_b^{nv})	π^{nv}	p_k	(Q_a,Q_b)	π	*Profit improvement*
10.1	(42.5, 44.8)	217.2	8.8	(43.9, 46.8)	237.6	9.4%
10.3	(43.0, 44.8)	225.1	8.9	(43.9, 47.3)	245.9	9.2%
10.7	(44.1, 44.8)	241.2	9.1	(43.7, 48.2)	262.1	8.6%
11.0	(44.8, 44.8)	253.5	9.2	(43.6, 48.9)	273.9	8.1%
12.0	(46.9, 44.8)	295.2	9.6	(43.0, 51.0)	311.4	5.5%
13.0	(48.5, 44.8)	338.1	9.9	(42.3, 52.8)	346.1	2.4%
14.0	(50.0, 44.8)	381.7	10.0	(41.4, 54.2)	377.5	−1.1%
16.0	(52.4, 44.8)	471.0	10.0	(39.5, 56.1)	428.1	−9.1%

Table 2
The effect of demand correlation on the decisions and performance gap.

ρ	(Q_a^{nv}, Q_b^{nv})	π^{nv}	p_k	(Q_a,Q_b)	π	*Profit improvement*
−0.9	(42.1, 44.8)	213.3	8.6	(45.3, 48.3)	242.7	13.8%
−0.5	(42.1, 44.8)	213.3	8.8	(43.9, 46.6)	233.4	9.5%
0	(42.1, 44.8)	213.3	9.0	(43.1, 45.7)	225.4	5.7%
0.5	(42.1, 44.8)	213.3	9.2	(42.6, 45.1)	219.0	2.6%
0.9	(42.1, 44.8)	213.3	9.6	(42.3, 44.8)	214.5	0.5%

Table 3
The effect of demand variation on the decisions and performance gap.

σ_b	(Q_a^{nv}, Q_b^{nv})	π^{nv}	p_k	(Q_a,Q_b)	π	*Profit improvement*
5	(42.1, 47.4)	230.6	9.1	(43.3, 48.7)	244.6	6.0%
10	(42.2, 44.7)	213.3	8.8	(43.9, 46.6)	233.4	9.5%
20	(42.1, 39.8)	180.9	8.5	(44.5, 42.1)	207.5	14.7%
30	(41.6, 37.1)	163.5	8.4	(44.4, 39.6)	192.5	17.7%
40	(41.0, 37.1)	157.5	8.4	(44.3, 39.6)	187.4	19.0%

Table 4
The effect of demand asymmetry on the decisions and performance gap.

$(\mu_a, \sigma_a, \mu_b, \sigma_b)$	(Q_a^{nv}, Q_b^{nv})	π^{nv}	p_k	(Q_a,Q_b)	π	*Profit improvement*
(10, 3, 90, 27)	(8.4, 75.9)	196.0	9.3	(12.4, 73.8)	206.7	5.4%
(20, 6, 80, 24)	(16.9, 67.4)	196.0	9.0	(21.6, 65.8)	213.1	8.7%
(30, 9, 70, 21)	(25.3, 59.0)	196.0	8.8	(29.7, 58.4)	217.1	10.7%
(40, 12, 60, 18)	(33.7, 50.6)	196.0	8.6	(37.2, 51.2)	219.3	11.9%
(50, 15, 50, 15)	(42.1, 42.2)	196.0	8.6	(44.3, 44.3)	220.1	12.3%

the negative effect of demand uncertainty and solve the mismatch between capacity and demand. Offering flexible products to potential buyers as additional purchase options, can also help increase a firm's revenue. Second, flexible products are offered at discounted prices, so they can stimulate and induce demand from a segment of customers who will not buy at regular prices, and thereby increase overall sales. We expect bigger discounts to induce more demand. The effect of demand induction definitely allows companies to generate more sales.

Although flexible products are beneficial in various ways, they may also introduce the negative effect of cannibalizing the regular-price demand for specific products. As flexible produces are priced lower than specific products, customers willing to buy products at their regular prices may end up paying a discounted price. Thus, demand cannibalization reduces revenue.

Table 5
The effect of salvage value on the decisions and performance gap.

s	(Q_a^{nv}, Q_b^{nv})	π^{nv}	p_k	(Q_a,Q_b)	π	*Profit improvement*
0	(42.1, 44.7)	213.3	8.8	(43.9, 46.6)	233.4	9.5%
1.5	(44.3, 46.2)	221.2	8.9	(45.5, 47.5)	238.4	7.8%
3.0	(47.3, 48.2)	231.4	9.0	(47.6, 48.6)	245.0	5.9%
4.5	(51.7, 51.2)	245.6	9.2	(50.9, 50.5)	254.7	3.7%
6.0	(60.1, 56.7)	268.3	9.5	(58.2, 55.0)	271.5	1.2%

Table 6
The effect of penalty on the decisions and performance gap.

p_t	(Q_a^{nv}, Q_b^{nv})	π^{nv}	p_k	(Q_a,Q_b)	π	*Profit improvement*
0	(42.1, 44.8)	213.3	8.8	(43.9, 46.6)	233.4	9.5%
1.5	(45.9, 47.3)	189.8	8.6	(45.9, 47.1)	223.8	17.9%
3.0	(48.5, 49.0)	171.2	8.4	(47.1, 47.2)	216.7	26.6%
4.5	(50.7, 50.4)	155.7	8.3	(48.0, 47.4)	211.0	35.5%
6.0	(52.4, 51.6)	142.6	8.2	(48.7, 47.4)	206.2	44.6%

Table 7
The effect of procurement cost on the decisions and performance gap.

c	(Q_a^{nv}, Q_b^{nv})	π^{nv}	p_k	(Q_a,Q_b)	π	*Profit improvement*
3	(57.9, 55.2)	613.3	9.0	(55.3, 53.1)	631.1	2.9%
4	(53.8, 52.5)	503.6	8.9	(52.3, 51.3)	525.1	4.3%
5	(50.0, 50.0)	400.5	8.8	(49.5, 49.8)	423.6	5.8%
6	(46.2, 47.4)	303.6	8.8	(46.9, 48.3)	326.3	7.5%
7	(42.1, 44.7)	213.3	8.8	(43.9, 46.6)	233.4	9.5%

To understand the benefits and risks of flexible products from an operations management perspective, we study a two-product newsvendor system with a flexible product as an additional purchase option. We consider a demand cannibalization model in which the total market demand remains the same, but with the cheap flexible product offer, a fraction of the demand switches from the specific products to the flexible product. We investigate the value of offering a flexible product in this setting and examine how a retailer should determine the optimal order quantities after introducing a flexible product, as well as the pricing decision of the flexible product. In reality, demand induction and demand cannibalization often coexist. Thus our model with pure demand cannibalization provides a conservative estimate on the value of offering flexible products. Even with two specific products, the problem is challenging to solve due to the multiple random sources. We believe the insights generated from the two-product system can be generalized to multi-product systems.

The remainder of this paper is organized as follows. We review the relevant literature in Section 2. In Section 3, we describe a general model with a flexible product to characterize the optimal inventory policy. We then discuss two special cases in Section 4. Numerical experiments are presented in Section 5. Finally, we conclude the paper in Section 6. All the proofs are shown in the Appendix.

2. Literature review

Flexible products have been studied in the literature on revenue management. Gallego and Phillips (2004) study an airline booking control problem with two flights (specific products) serving the same route and a flexible product assigned to one of the two flights in a two-period setting. In the first period, the airline offers both the specific products and the flexible product at a discounted fare. In the second period, only the specific products are sold. The authors investigate how booking control policies affect revenue.

Another stream of closely related literature is on probabilistic goods,