Active response of strategic consumers to stockout

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Abstract. We develop a game-theoretical model of a supply chain consisting of two retailers that sell two substitutable products at regular prices over a finite season which ends with clearance sales at reduced prices. There are strategic consumers who anticipate future discounts and non-strategic consumers who purchase at the regular price if it is less than their reservation price. When a product stockout happens, a customer may switch to a substitutable product, switch to another store, or delay purchase. We find that such active response to stockout is likely to result in lower stock levels which would affect the propensity of strategic consumers to wait for future markdowns. This could mitigate negative consequences of product shortages for retailers and allow charging higher regular and clearance prices. We compare systems with alternative compositions of consumers and levels of active response to stockout and discuss how retailers could control strategic consumer behavior.

Keywords: Game theory, Marketing-operations interface, Strategic customers, Product substitution.

1. INTRODUCTION

Regular price promotions trained many consumers to only spend during clearance sales. The recent demise of department stores and specialty chains was largely attributed to frequent promotions of fashion products. Still, majority of U.S. retailers do not have an effective strategy for management of prices and promotions across all channels (Sourcing Journal, 2016). Understanding how strategic consumers (also known as forward looking consumers) weigh their gain from future discounts against stockout risks in case of delayed consumption is important for development of right pricing strategy. Four alternative responses of customers represent common outcomes of product shortage: lost sales, brand switching, store switching, and delay (Corsten and Gruen, 2005). We define delay (backorder), brand and store switching as "*active response to stockout*". In particular, one interesting aspect of responses to stockout is central to our research: how possibilities of backordering, brand and store switching affect the propensity of strategic consumers to wait for future markdowns.

Su and Zhang (2008) investigate possibility of using contracts for supply chain coordination with strategic consumers. Cachon and Swinney (2009), and Cachon and Swinney (2011) are among the researchers who model how quick response helps in dealing with strategic consumers by reducing the probability of unsold inventory remaining for the clearance sales due to better match of supply and demand. All of the abovementioned research is similar to our research in that our model also takes into account consumer valuations, probability and discount from future consumption. In particular, game-theoretical model of Cachon and Swinney (2011) is used to compare optimal order sizes, equilibrium full prices, and expected profit in traditional, quick response, enhanced design and fast fashion systems in presence of strategic consumer behavior. Their conclusion is that operational and behavioral components of quick response and enhanced design systems, being combined into a fast fashion system, tend to act as complements and the incremental value for profitability is even greater with strategic consumers. A distinction between our paper and the original paper by Cachon and Swinney (2011) is that latter mainly considers only what conditions make one of four production systems more profitable strategy than other for fashion firms. Meanwhile, our model focuses on how responses to stockout interact with forward looking behavior of strategic consumers. Consequently, we do not consider production modes in our model but compare two models: a base model

of strategic consumers (with no active response to stockout) and a model where those consumers have an option of backordering, brand and store switching. Furthermore, we consider both regular and clearance prices in equilibrium.

We extend newsvendor model with active response to stockout which was formulated by Kurata and Ovezmyradov (2014), and Ovezmyradov and Kurata (2015) by means of incorporating strategic consumers. Our extension focuses on responses to stockout by strategic consumers in fashion supply chain settings. Previous modeling research on responses to product stockout include Anupindi and Bassok (1999), Rajaram and Tang (2001), Mishra and Raghunathan (2004), Netessine and Zhang (2005). These researchers conclude that the demand substitution between products likely has a positive impact on expected profits. To the best of our knowledge, there was no modeling research that provided findings on implications of product substitution on behavior of strategic consumers. The research question of our paper is: how do backordering, brand and store switching affect the forward looking behavior of strategic consumers? The rest of the paper is organized as follows. In Section 2 we present a base model of strategic behavior of consumers. In Section 3, we analyze an extended model of active response of strategic customers to stockout. In Section 4, we separately analyze the case of exogenously set regular price. Section 5 describes conducted simulations and shows managerial implications. Section 6 presents a summary.

2. BASE MODEL

Our model considers a single-period supply chain of two fashion retailers: Retailer 1 and Retailer 2. Each of the retailers sells two substitutable brands and implements make-to-stock production system. Brands, indexed i and j, have a regular price, p; wholesale price, w; discounted clearance sales price, v at the end of sales season. Further, to avoid unrealistic outcomes, $p > w$ and $v < w$. Our model relies on the following assumptions made for tractability and comparability of results. There is no shortage cost per a unit of lost sales. Value of unsold inventory, v, is not a salvage value as in common newsvendor problems but the final clearance price per unit set by the retailer at the end of sales season (for instance, winter or summer sales of apparel). In addition to strategic consumers, there are bargain-hunters who only buy during clearance sales. The unsold inventory remaining by the start of the sales at discount is first allocated to strategic consumers and the remainder after, if any, is available to unlimited number of bargain hunters so that all overstock is sold finally. Similar assumptions of bargain-hunters and an analogy between salvage market and discounted sales during clearance period were made by Cachon and Swinney (2009). Retailers are assumed to be homogeneous in sold brands, pricing strategy, internal costs, bargaining power and search costs for visiting customers. The random non-negative demand is assumed to follow normal distribution. Each customer buys one unit of fashion brand so the total demand is equal to the number of customers in the local market. Orders of any size, including additional backorders, can be placed from suppliers of each retailer. Again, these are all common assumptions made in many similar studies. Figure 1 gives outline of our model of supply chain structure while Table 1 shows notations used in our model.

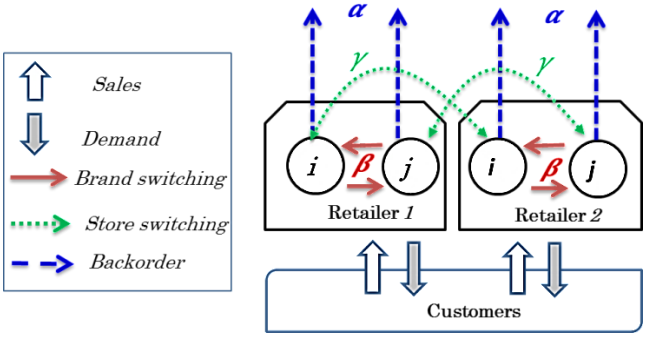

Figure 1: Supply chain structure.

Table 1: Notations and Symbols.

p	Unit retail price
w	Unit wholesale price
$\boldsymbol{v}$	Unit clearance price
π	Expected profit
q	Order size of retailer
α	Portion of backordering customers
β	Portion of brand-switching customers
γ	Portion of store-switching customers
$f(x)$	Probability density function of demand
$F(x)$	Cumulative distribution function of demand
μ, σ	Mean and standard deviation of demand
0	Notation of the classic newsvendor model with absence of strategic behavior of consumers
C	Notation of the newsvendor model with strategic behavior of consumers
A	Notation of the model of active response to stockout
V	Notation of the model with exogenous regular price
$n \in [i, j]$	Product brands
$m \in [1,2]$	Stores of retailers
u	Consumers' reservation price
d	Discount of future consumption by consumer
r	Consumers' perceived probability of future discount

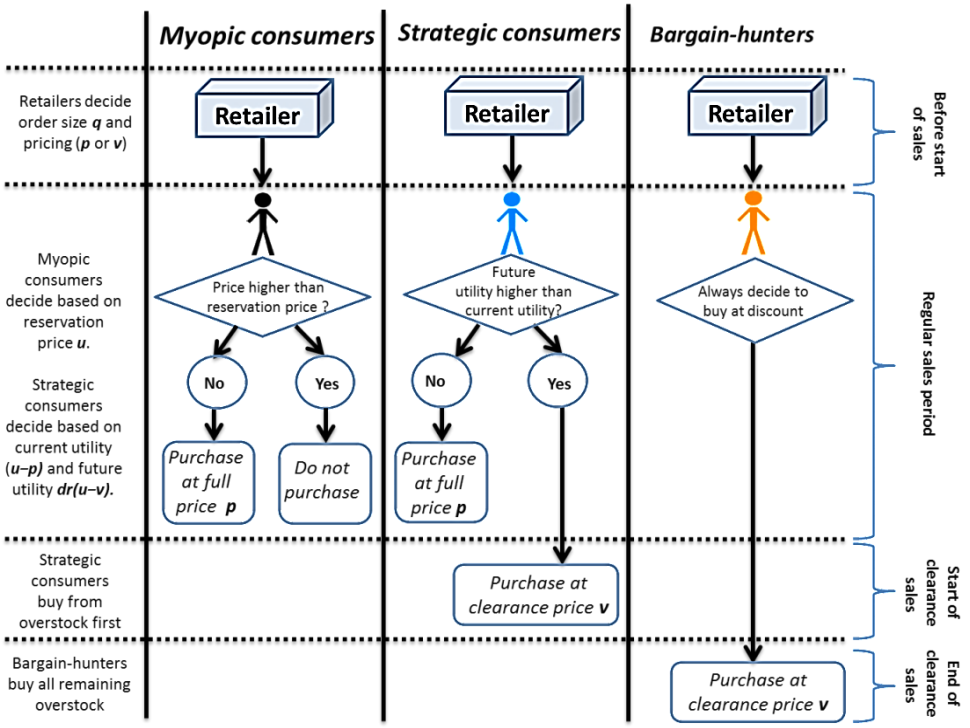

Figure 2: Sequence of actions by retailers and consumers (note that the current utility must be nonnegative in order for strategic consumers to purchase at full price).

From a newsvendor model's expression, expected profit of Retailer 1 from a product i can be formulated as follows:

$$\pi_{1,i}^{C} = p_{1,i}S_{1,i} - w_{1,i}q_{1,i} + v_{1,i}I_{1,i} \quad (1)$$

Where expected ***sales of Brand i at Retailer 1*** is $S_{1,i} = p_{1,i}\int_0^{q_{1,i}} x_{1,i}\, f(x_{1,i})dx_{1,i} + p_{1,i}q_{1,i}\int_{1,i}^{\infty} f(x_{1,i})dx_{1,i}$;

the expected ***overstock of Brand i at Retailer 1*** is $I_{1,i} = \int_0^{q_{1,i}} (q_{1,i} - x_{1,i}) f(x_{1,i})dx_{1,i}$.

The first term in Eq. (1) expresses the expected revenue, the second term is a purchasing cost, the last term is the expected revenue from clearance sales at discounted a price. Expressions of expected profit for other brands and stores can be found in identical manner.

Figure 2 shows the model of behavior of strategic consumers in our research which generally follows Cachon and Swinney (2011). In the game between strategic consumers and the retailer, we model the intensity of forward looking behavior by parameter d ($0 \le d \le 1$) which denotes discount of future consumption by consumers. In extreme case of $d = 0$, all consumers are *myopic*: they would not wait for future discounts and buy immediately if the regular price is equal to or less than their u reservation price. This is the most desirable situation for retailer since the regular price can be set equal to reservation price, u, ensuring maximum profit. Situation changes for worse with *strategic* consumers who have a belief about the likelihood of unsold products still remaining during clearance sales, r (probability of overstock, $0 \le r \le 1$). This probability is equal to the average probability of a clearance sale in the future: rational expectation of overstock by consumers would be correct in equilibrium. Consumers are all assumed to have an equal reservation price (this is the maximum price that consumers are ready to pay which is equal to personal utility of product consumption). Even though restrictive for realistic situations, this assumption is made for simplicity in our and related research (Cachon and Swinney, 2011). Therefore all consumers either purchase at regular price, p, or clearance price, v. There is Nash equilibrium in this game between the retailer and homogeneous consumers. We do not consider the equilibrium where consumers purchase at clearance price since retailer would not be interested at selling all stock at clearance price. We focus instead only on equilibrium where a retailer induces all consumers to buy at a regular price. Let p_0^* denote equilibrium regular price with myopic consumers ($d = 0$) while p_C^* denote corresponding price with strategic consumers ($d > 0$). Similarly, the expected profit is denoted π^0, in case of $d = 0$; or π^C, in case of $d > 0$. We consider two alternative pricing strategies: (i) fixed discount where clearance price is exogenous while equilibrium regular price is defined by the model; (ii)

contingent discount where regular price is exogenous while equilibrium clearance price is defined by the model. This Section 2 and the next Section 3 focus on the first strategy while the Section 4 considers the second strategy. Note that both pricing strategies exist in retailing practice and are reflected in academic literature (Aviv and Pazgal 2008). Majority of similar research employing newsvendor model (including Cachon and Swinney 2011, Su and Zhang 2008) assume v to be exogenous salvage value. While first focusing on fixed discount strategy, we also acknowledge important case of exogenous price in a separate section. We now present findings of the base model without active response to stockout.

Proposition 1. *With the classic newsvendor model settings, there exists unique Nash equilibrium with nonzero production where all consumers purchase early. In the equilibrium, regular price and expected profit of retailer with strategic consumers will be lower than with myopic consumers.*

(a) $p_C^* \leq p_0^*$.

(b) $\pi^0 \geq \pi^C$.

(c) $\frac{\partial \pi^C}{\partial d} < 0$.

Proof. In the equilibrium with rational expectations and nonzero production, the retailer decides on price and inventory to maximize expected profit, given that consumers all purchase at regular price.

$$(q^*, p^*) = \operatorname{argmax}_{q,p} \pi(q, p)$$

Consumers would purchase early, given the regular price and a belief about the probability of a clearance sale so that $u-p* \geq dr(u-v)$. Consumer belief about the probability of a clearance sale is rational, therefore $r = F(q_C^*)$. Rewriting Eq. (1) as

$$\pi_{1,i}^A = p_{1,i}\int_0^{q_{1,i}} x_{1,i}\, f(x_{1,i})dx_{1,i} + p_{1,i}q_{1,i}\int_{1,i}^{\infty} f(x_{1,i})dx_{1,i} -$$

$$w_{1,i}q_{1,i} + v_{1,i}\max \int_0^{q_{1,i}} (q_{1,i} - x_{1,i}) f(x_{1,i})dx_{1,i} \ ,$$

and from the first-order condition of this equation using Leiniz's rule, the optimal inventory level satisfies $F(q_C^*) = (p-w)/(p-v)$. In such equilibrium. if the retailer decides to hold the optimal inventory as per $F(q_C^*)$, and if consumers have rational expectations, all consumers purchase at initial price because their current net utility from consumption at regular price is higher than the expected net utility in the future from consumption at clearance price: $u-p \geq dr(u-v)$. When expectations of consumers are rational, the likelihood of future bargain, r, becomes equal to the actual probability that a consumer deviating from the equilibrium (those who decide to wait to buy during the clearance sale) is expected to get the overstock product at clearance price. This is possible only if the firm has enough inventory, q^*, to satisfy all the demand. Therefore, $r = Pr(x \leq q_C^*) = F(q_C^*)$. Deciding on the regular price, the retailer maximizes expected profit by choosing the maximum price satisfying $u-p \geq dr(u-v)$. Hence the optimal regular price would be set equal to $p=u-dr(u-v)$. Considering $r = F(q_C^*) = (p-w)/(p-v)$, the regular price can be defined as $p=u-d(p-w)(u-v)/(p-v)$. Rearranging this expression, the equilibrium regular price can be obtained

$$p^* = (u+v-du+dv \mp (-(u-v)(v-u-4dw+2du+2dv-d^2u+d^2v))^{1/2})/2$$

There are two equilibria here, however the lower regular price at equilibrium is less than purchasing cost ($p < w$), and can be rejected as unrealistic for retailing. Hence a unique equilibrium exists which satisfies the conditions where regular and clearance prices decrease in d which, in turn, leads to lower expected profit of retailer. □

Note that the result of Proposition 1 for regular price in equilibrium is the same with Cachon and Swinney (2011) since our base model and corresponding proof coincide with their research. Obviously, the more intense effect of strategic consumers, the worse is detrimental impact on profitability.

3. ACTIVE RESPONSE TO STOCKOUT

With backordering, in response to stockout, some α portion of consumers delays purchase by asking for later delivery. With brand β and store γ switching portions of consumers, surplus from one product is used to substitute a certain portion of spillover demand for another stockout product. Consequently, $0 \leq \alpha, \beta, \gamma < 1$; $0 \leq \alpha+\beta+\gamma < 1$. Then expected profit of Retailer 1 from a product i with active response to stockout can be formulated as follows (results for other store and brand can be found in analogous manner):

$$\pi_{1,i}^A = p_{1,i}S_{1,i} - w_{1,i}q_{1,i} + (p_{1,i} - w_{1,i})\,\alpha_{1,i}\,L_{1,i} + p_{1,i}\min\{(\beta_{1,j}L_{1,j} + \gamma_{2,i}L_{2,i}), I_{1,i}\} + v_{1,i}\max\{(I_{1,i} - \beta_{1,j}L_{1,j} - \gamma_{2,i}L_{2,i}),\ 0\} \qquad (2)$$

Where expected ***stockout of Brand i at Retailer 1*** is

$$L_{1,i} = \int_{q_{1,i}}^{\infty} (x_{1,i} - q_{1,i}) f(x_{1,i}) dx_{1,i} \ ;$$

the expected ***stockout of Brand j at Retailer 1*** is

$$L_{1,j} = \int_{q_{1,j}}^{\infty} (x_{1j} - q_{1,j}) f(x_{1,j}) dx_{1,j} \ ;$$

the expected ***stockout of Brand i at Retailer 2*** is

$$L_{2,i} = \int_{q_{2,i}}^{\infty} (x_{2,i} - q_{2,i}) f(x_{2,i}) dx_{2,i} \ ;$$

In addition to the previously described terms, here the

third term indicates additional profit due to backordered items in case of stockout, and the fourth term represents the additional expected sales revenue due to brand and store switching. Note that without active response to stockout ($\alpha=\beta=\gamma=0$), Eq. (2) would turn to expected profit expression of a classic newsvendor model ($\pi_{1,}^{0}$ or $\pi_{1,}^{C}$). Let p_C^* and v_C^* denote equilibrium prices with strategic consumers ($d > 0$). For comparability and tractability, active response levels of customers at both stores are set equal, so that $\beta_{1,i} = \beta_{1,j} = \beta_{2,i} = \beta_{2,j}$, $\gamma_{1,i} = \gamma_{1,j} = \gamma_{2,i} = \gamma_{2,j}$. We now consider active response to stockout in Proposition 2 and make comparisons with results of Proposition 1.

Proposition 2. *Under the model of active response to stockout, and assuming symmetrical retailers, when levels of backordering and brand and store switching for each store and brand are low to average, there exists unique Nash equilibrium where all consumers purchase at regular price. In this equilibrium, regular prices with active response to stockout will be higher than when there is no such response.*

(a) $q_C^* \geq q_A^*$.

(b) $p_C^* \leq p_A^*$.

(c) $\frac{\partial p_A}{\partial \alpha} > 0, \frac{\partial p_A}{\partial \beta} > 0, \frac{\partial p_A}{\partial \gamma} > 0$.

(d) $\frac{\partial \pi_A}{\partial \alpha} > 0, \frac{\partial \pi_A}{\partial \beta} > 0, \frac{\partial \pi_A}{\partial \gamma} > 0$.

Proof. Equilibrium settings follow immediately from Proposition 1 by adjusting expected profit expression and adding active response to stockout. Rewriting Eq. (2) as

$\pi_{1,i}^{A} = p_{1,i}\int_0^{q_{1,i}} x_{1,i}\ f(x_{1,i})dx_{1,i} + p_{1,i}q_{1,i}\int_{1,i}^{\infty} f(x_{1,i})dx_{1,i} - w_{1,i}q_{1,i} + (p_{1,i} - w_{1,i})\alpha_{1,i}\int_{q_{1,i}}^{\infty}(x_{1,i} - q_{1,i})f(x_{1,i})dx_{1,i} + p_{1,i}min\left\{\beta_{1,j}\int_{q_{1,j}}^{\infty}(x_{1,j} - q_{1,j})f(x_{1,j})dx_{1,j} + \gamma_{2,i}\int_{q_{2,i}}^{\infty}(x_{2,i} - q_{2,i})f(x_{2,i})dx_{2,i}, \int_0^{q_{1,i}}(q_{1,i} - x_{1,i})f(x_{1,i})dx_{1,i}\right\} + v_{1,i}max\left\{\int_0^{q_{1,i}}(q_{1,i} - x_{1,i})f(x_{1,i})dx_{1,i} - \beta_{1,j}\int_{q_{1,j}}^{\infty}(x_{1,j} - q_{1,j})f(x_{1,j})dx_{1,j} - \gamma_{2,i}\int_{q_{2,i}}^{\infty}(x_{2,i} - q_{2,i})f(x_{2,i})dx_{2,i}, 0\right\}$,

the optimal inventory level can be derived from the first-order conditions of Eq. (2) and we omit indices for brevity.

$$F(q_A^*) = \begin{cases} K & if \quad (\beta+\gamma)\int_q^{\infty}(x-q)f(x)dx \geq \int_0^{q}(q-x)f(x)dx \\ \frac{p(1-\alpha-\beta-\gamma)+\alpha(k+w)-w+v(\beta+\gamma)}{p(1-\alpha-\beta-\gamma)+\alpha(k+w)+v(\beta+\gamma)-v} & if\ otherwise \end{cases}$$

where K is the profit maximizing solution that satisfies $(\beta+\gamma)\int_q^{\infty}(x-q)f(x)dx = \int_0^{q}(q-x)\,f(x)dx$.

We further focus our attention only on low to average levels of α and β and γ so that $F(q_A^*) \neq K$ and therefore

$$F(q_A^*) = \frac{p(1-\alpha-\beta-\gamma)+\alpha(k+w)-w+v(\beta+\gamma)}{p(1-\alpha-\beta-\gamma)+\alpha(k+w)+v(\beta+\gamma)-v}$$

Analysis of this critical ratio reveals that optimal order size would be lower than with traditional newsvendor when levels of active response to stockout are positive. Following from the critical ratio is the equilibrium price

$$p = u - d\left\{\frac{p(1-\alpha-\beta-\gamma)+\alpha(k+w)-w+v(\beta+\gamma)}{p(1-\alpha-\beta-\gamma)+\alpha(k+w)+v(\beta+\gamma)-v}\right\}(u-v)$$

Simplifying this expression and solving for p gives an expression for regular price where Proposition 2 statements directly follow from comparison between equilibrium prices in Proposition 1 and 2. □

Overall, the effect of strategic consumers who have options of active response to stockout is likely to result in retailers charging higher regular price and holding less stock and earning higher profits.

4. EXOGENOUS REGULAR PRICE

In this section we deal with an extension of the previous model addressing contingent pricing strategy where regular price is exogenous (unlike in the previous sections where discount price was assumed to be fixed). Let equilibrium clearance price be denoted v_0^* with the classic newsvendor and myopic consumers ($d = 0$), while v_C^* denote corresponding price with strategic consumers ($d > 0$). Finally, let v_V^* denote equilibrium clearance price in presence of active response to stockout and $\pi_{V,}$ the expected profit, correspondingly.

Proposition 3. *Under the model of active response to stockout and given exogenous regular price, assuming symmetrical retailers, when levels of backordering and brand and store switching for each store and brand are low to average, there exists unique Nash equilibrium in which clearance price with active response to stockout will be higher than when there is no such response.*

(a) $v_C^* \leq v_A^* \leq v_0^*$.

(b) $\frac{\partial v_V^*}{\partial \alpha} > 0, \frac{\partial v_V^*}{\partial \beta} > 0, \frac{\partial v_V^*}{\partial \gamma} > 0$.

(c) $\frac{\partial \pi_V}{\partial \alpha} > 0, \frac{\partial \pi_V}{\partial \beta} > 0, \frac{\partial \pi_V}{\partial \gamma} > 0$.

Proof. The proof follows immediately from Propositions 1 and 2, by adjusting equilibrium price expression with

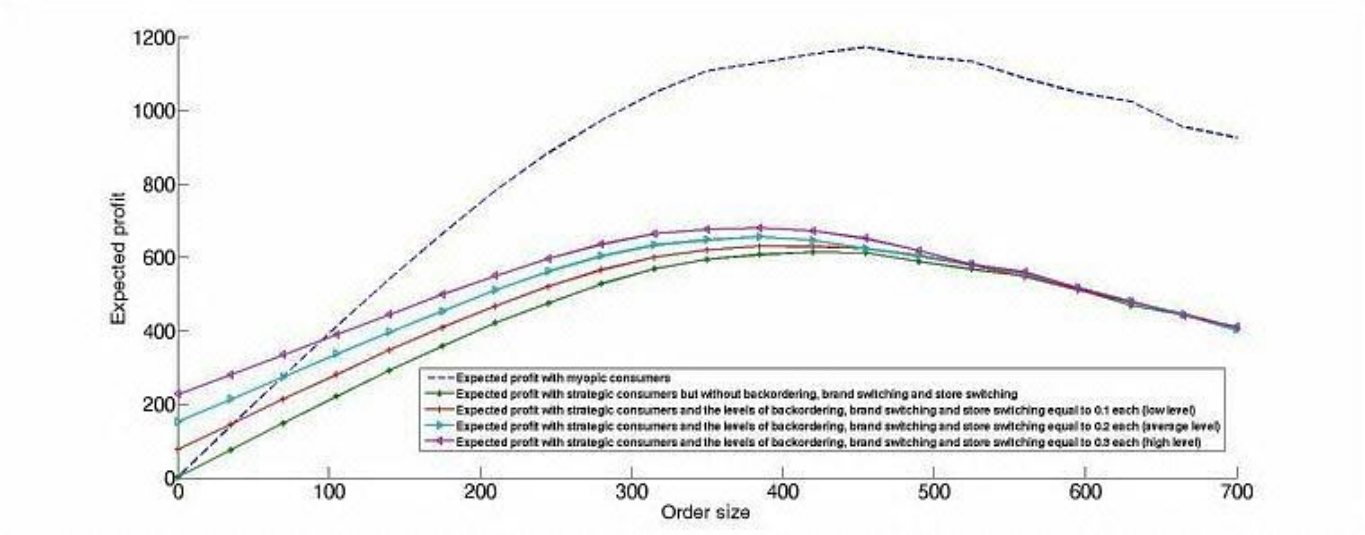

Figure 3: Active response level and expected profit.

rearrangement for clearance price and direct comparison with results of Propositions 1 and 2 (with active response to stockout, there are two equilibria where higher one is unrealistic since it leads to $v > p$, so there remains one unique equilibrium). □

The contingent clearance pricing strategy could be more relevant for certain category of apparel retailers (for example, lower priced mass-produced apparel in a mature market) facing regular pricing dictated by competition in the same segment of market or by internal cost structure of the retailer. In such cases it could be optimal to adjust clearance price for profit optimization. Results of higher equilibrium clearance prices and expected profits with active response to stockout here are similar to that of Proposition 2 meaning findings of our research, in general, hold with both pricing strategies.

5. SIMULATION AND DISCUSSION

To illustrate impact of active response, we conduct a numerical experiment in which arbitrarily set $\alpha=\beta=\gamma$ (horizontal axis in Figures 4 and 5 represents the total level of active response to stockout, $\alpha+\beta+\gamma$). Further, we set $d=0.6$, $w=4$, $v=2$, $\mu=350$ and $\sigma=100$. Figure 3 shows comparison of profitability with different levels of forward looking behavior and active response to stockout. Substantial loss of expected profit can be observed: profits are nearly halved because of 40% lower valuation of future consumption by strategic consumers ($d=0.6$) as compared to myopic consumers ($d=0$). Meanwhile, introduction of active response to stockout helps partially compensate for this loss and reduces risks of understocking.

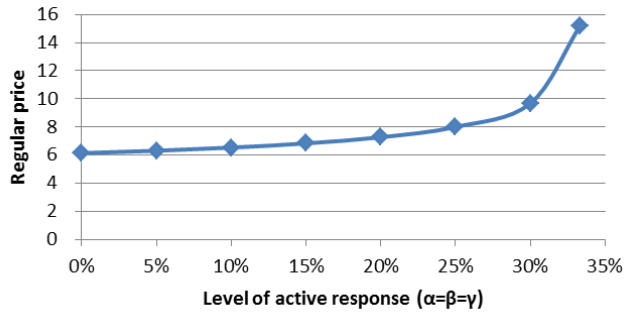

Figure 4: Regular price change with active response.

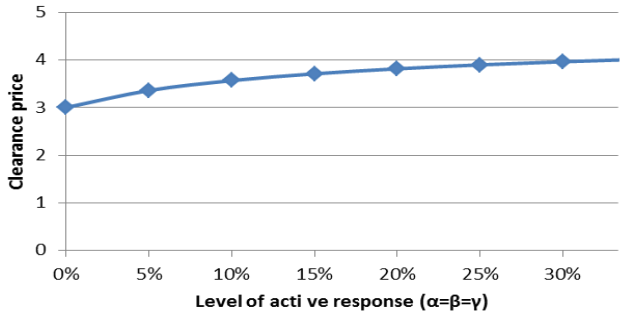

Figure 5: Clearance price change with active response.

Exogenous clearance price is set $v = 2$ in Figure 4. Exogenous regular price is set $p = 6$ in Figure 5. Interestingly, results for Figure 3 are not visibly affected from choice of pricing strategy (the expected profits are approximately the same with either regular or clearance price set exogenous). Simulation results from Figures 4 and 5 seem to support Propositions 2 and 3 findings, correspondingly. Both regular and clearance prices in

equilibrium increase in α, β and γ. The increase in the level of active response seems to be more pronounced with regular prices than with clearance pricing. Retailers are likely to hold less stock while charging higher prices as the benefit of the higher stockout risk for consumers and at the same time increasing clearance prices to reduce future expected utility of strategic consumers from waiting for discounts. Fast fashion retailers such as Zara achieved their remarkable success not least because of deliberately understocking in order to have less overstock to be sold at clearance prices (Fernie et al 2009). Understocking reduces negative effects of strategic consumer behavior (willingness to wait for future discounts). However, such practice also results in greater probability of lost sales.

The managerial implication of our findings is that retailers should consider substitutability and strategic consumers when designing supply chains and omnichannel strategies. This issue concerns not only cooperating stores: independent retailers could also cooperate to design operations in a manner that mutually encourages active response of customers to stockout. For stores belonging to the same retailing chain, omnichannel capabilities provide very favorable conditions for managing responses to stockout with use of mobile interfaces, in-store pickup, online reservation and loyalty programs all of which could facilitate an easy access to data on product availability and alternative shopping location. Our findings suggest how to implement a stock reduction coupled with higher prices to balance match and demand in presence of strategic consumers and active response to stockout.

6. CONCLUSION

In retailing practice, active response of consumers to stockout is often observed which includes backordering, brand switching and store switching. We develop a model of active response to stockout incorporating strategic consumer behavior. Active response of strategic consumers to stockout is likely to result in lower stock levels while leading to higher regular and clearance prices of retailers. Presence of strategic consumers generally results in lower expected profits of retailers, but active response to stockout help mitigate this negative effect.

It should be noted that the presented analysis was based on an assumption of homogeneous consumers with same valuations. Analyzing a model where consumers have uncertain valuations with some distribution of probabilities could become an interesting direction of future research. Another extension could relax the assumption that strategic consumers are allocated leftover inventory first preceding any other bargain hunters, for instance, as implemented by Cachon and Swinney (2009).

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