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Analysis of the Impact of Demand Volatility and Return Policies on a Price-setting Newsvendor

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Abstract: This paper studies a newsvendor problem in which the retailer can set both the selling price and the quantity ordered. The demand is stochastic and price-dependent and the retailer has the possibility to sell his unsold units at the end of the sales season. We present an analytical model of the retailer optimization process and show the conditions that the retailer can find optimal quantity and price simultaneously, then we use numerical methods to reveal the properties of retailer's behavior. The existing results of price-setting newsvendor do not include buyback and our work brings a new condition on the lost sales rate elasticity for the computation of an optimal solution. Our results show that return policies can improve the profit of retailer and that this effect increases with the volatility of the demand. This observation reveals a crucial point for the supplier to design their contract according to demand uncertainty, allowing them to influence the retailer's decision on price and order quantity by offering buy-back for unsold products.

Keywords: Supply chain, price-dependent, newsvendor, return policy.

1. INTRODUCTION

Independent retailers play a vital role in the distribution channel of products, and the suppliers in different industries are relying on them to optimize the distribution of their products thanks to their superior knowledge about the market, economies of scale, reputation, among other reasons (Emmons and Gilbert (1998)). As a consequence, it is essential to understand retailers' behavior when they receive a contract from the suppliers, from which they can derive their ordering decisions. In this regard, retailers should integrate the features of the contract into their decision-making process, together with their (private or public) information on the demand, the market price and their correlation. In this study we consider a profit maximizing retailer who has the possibility to set his retail price besides his order quantity. In particular, an increase in price can lead to a decrease in demand, reducing in turn his order quantity. The challenge for the retailer is therefore to find an optimal price and quantity in order to maximize his profit.

1.1 Motivation of this work

The features of market demand and its relation with price is a cornerstone in retailers' reactions to the different contracts. When the suppliers choose their return policy to buy back the unsold of products of the retailers by the end of selling season, the question is, can they decide about return policies only based on the features of market demand? The answer to this question lies down on the behavior of retailers.

The sequence of events we consider is as follows: At time 0, the retailer receives a take-it-or-leave-it wholesale price contract with buy-back. The retailer reacts to the supplier's contract by simultaneously setting an order quantity and a retail price, which has negative effect on demand size. Note that the retailer can reject the contract, in which case both parties make zero profit. However, if the retailer accepts the contract, he decides both the order quantity and the retail price. All of the above decisions occur in the first stage at time 0. At the end-of-the-sales season, the demand is realized, the retailer returns unsold products to the supplier and receives the salvage value for each unit of returned product. Timeline of events is shown in Figure 1.

We model the demand faced by the retailer during the selling season as a decreasing function of the price, which means that increasing the price may reduce the profit of the whole supply chain. The retail price can be influenced by changes in the exogenous parameters, the wholesale price or salvage value of the products. If the wholesale price increases, the retailer may choose to increase the retail price, which will lead to a decrease of the demand, inducing a decrease of the retailer's order quantity. Hence

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it is crucial for the suppliers to understand the reaction of the retailer to different contracts.

1.2 Notation and Assumptions

We consider a simple supply chain composed of one retailer, who receives from his supplier a contract including a wholesale price w (the retailer ordering cost) and a buy-back price s, which he can use to return unsold units at the end of the sales season. The retailer has a single opportunity to order q units from the supplier before the sales season to satisfy an uncertain future demand. In addition, the retailer also controls the retail price p, which has a negative effect on the stochastic demand. We model this effect by defining the demand as a function $d(p, Z)$, decreasing in p and strictly increasing in Z, where Z is random variable with price-independent cdf Φ, pdf ϕ and complementary cdf $\bar{\Phi}$. To shorten the notations, we will often write $\mathbf{D}(p) = d(p, Z)$ to refer to the price-dependent random variable corresponding to the final customer demand with respect to price p. The support of $\mathbf{D}(p)$ is $[0, +\infty)$ for all $p \geq 0$ and we also assume that $d(p, z)$ is twice differentiable in p and Z. In this study, we restrict our attention to a linear additive demand model. In this particular case, the demand function has the form:

$$\mathbf{D}(p) = Z - bp, \tag{1}$$

where b is a strictly positive constant. Intuitively in the additive demand model, price moves the location of distribution, i.e. an increase in retail price induces a decrease in customers' demand, without affecting the shape of the demand distribution. The retailer is a profit-maximizing firm who seeks to optimize its order quantity and retail price decisions. Note that if $w \geq p$, the retailer cannot expect any profit by selling units, therefore he does not order any product. In addition if $w \leq s$, the retailer earns a risk-less profit by ordering as much as possible. As a consequence to avoid trivial cases, we assume in the remainder of this paper that:

$$p > w > s \geq 0. \tag{2}$$

The notations and symbols are summarized in Table 1.

2. STATE OF THE ART

In this paper we construct a model for the retailer's reaction to the offered contract to satisfy a stochastic demand, then we examine the effect of return policies on his optimal decisions.The contracts with return policies are commonly used in many industries such as fashion apparel, publishing, and cosmetics (He et al. (2009))and in such industries, the retailers need to decide the retail price before the selling season. Emmons and Gilbert (1998) studied the effect of return policies on both retailer's and manufacturer's profit under a multiplicative demand case in a price-setting newsvendor problem. They illustrate that for a given wholesale price, the offer of buying-back excess products from the retailer would increase the whole supply chain channel and manufacturer profit. Petruzzi and Dada (1999) analyze the newsvendor problem when order quantity and retail price are decided simultaneously.They show that in a stochastic additive demand model, optimal price is always lower than the deterministic case and in a stochastic multiplicative demand model, the optimal price would always be higher than deterministic one. They state that the optimal decisions depend on how uncertainty is introduced in the model. Yao et al. (2008) show that the profit of the retailer and the manufacturer both decrease when demand variability increases in an additive demand model. The same effect is examined by Xu et al. (2010), who explain that less variable demand leads to higher price in the additive demand model and lower price in the multiplicative demand model, but induces a higher expected profit in both cases. Kocabıyıkoğlu and Popescu (2011) proposed a new concept, called the lost sales rate (LSR) elasticity which corresponds to the percentage change in the rate of lost sales with respect to the percentage change in price for a given quantity. They proposed sufficient conditions on LSR elasticity for the uniqueness of optimal solutions in both sequential and simultaneous price-inventory optimization for the revenue function. General conditions to compute the optimal price are also proposed by Xu et al. (2011) in the multiplicative demand case and by Rubio-Herrero et al. (2015) under additive case for risk-averse and risk-seeking retailers without return policies consideration. In particular, the conditions proposed by Xu et al. (2011) impose that the random part of the demand has an increasing generalized failure rate (IGFR), while the mean demand has an increasing-price elasticity (IPE). Luo et al. (2016) consider more general demand model which is an additive-multiplicative demand. They show that the unimodality of expected profit function holds when the stochastic term of demand model has an IFR distribution and the demand function satisfies certain concavity conditions. They reveal the negative relation between optimal price and order quantity. Lu and Simchi-Levi (2013) studied the shape of profit function for price/quantity determination models and show that it is log-concave for many stochastic demand functions. They addressed a conjecture proposed in Petruzzi and Dada (1999) stating that when demand volatility decreases in price while the coefficient of variation of demand increases with price, a stable relation emerges between optimal price in stochastic and deterministic models.

Ye and Sun (2016) considered price-setting newsvendor

Symbol	Description
s	Salvage of value of each unsold product.
w	Supplier's wholesale price.
p	Retailer's selling unit price of the product.
q	Retailer's order quantity.
Z	A random variable.
$d(p, Z)$	Customers demand of the product at time T, as a function of p and Z.
$\phi(.)$	The probability density function (pdf) of Z.
$\Phi(.)$	The cumulative density function (cdf) of Z.
$\bar{\Phi}(.)$	The complementary cumulative density function of Z.

Table 1. Notations and symbols

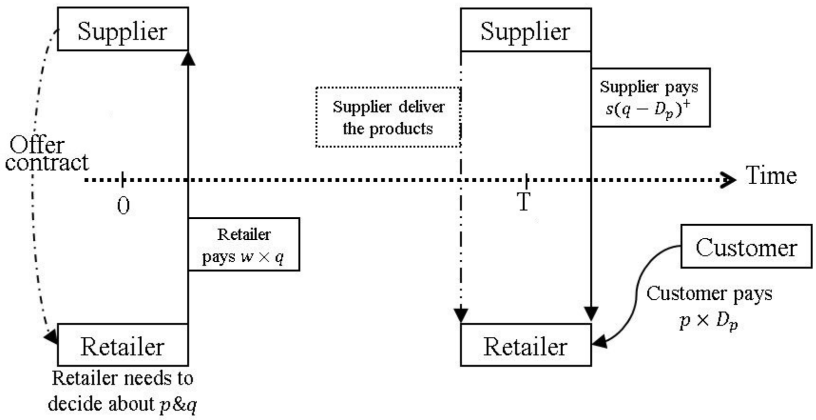

Fig. 1. Timeline of the events.

problem with strategic consumers who may decide to postpone their purchase to possibly buy the product on the salvage market. They show that all strategic consumers buy the product immediately. Kyparisis and Koulamas (2018) analyze the price-sensitive newsvendor problem with non-negative linear additive demand. They show that the problem still has an optimal solution (possibly nonunique), that can be computed for the certain distributions when the expected profit function is quasi concave. Basu et al. (2018) investigate hedging demand uncertainty in a supply chain under a buy-back contract in quantity decisions. They analyze the results for both observable and unobservable risk types of the retailer, and they proposed a new contract (option buyback contract) for unobservable case, to maximize total supply chain profit.
In this paper, we model a retailer's profit function under an additive demand model that includes a salvage value for unsold products. We generalize the approach introduced by Kocabıyıkoğlu and Popescu (2011) to determine conditions for the profit function to be jointly concave in price and quantity. Next, we show numerically that the optimal price, quantity and profit under an additive stochastic demand is always lower than in the deterministic model. Finally we examine how return policies can mitigate the effect of demand uncertainty on the optimal decisions of the retailer.

3. MODEL DESCRIPTION

Recall that at the beginning of the planning horizon, the retailer is offered a contract (w, s) upon which he can optimize his expected profit. Knowing the expression of the demand function, the retailer needs to optimize jointly p and q in order to maximize his profit. For a given realization z of the r.v. Z, we can distinguish between two scenarios:

(1) The realized demand is lower than the order quantity ($Z \leq q + bp$), then the profit of the retailer is the following:

$$\begin{aligned}\pi_r(p, q) &= p(z - bp) + s(q - z + bp) - wq\\ &= (p - s)(z - bp) - (w - s)q.\end{aligned}$$

(2) The realized demand is higher than the order quantity ($Z > q + bp$), in which case the profit of the retailer is expressed as follows:

$$\pi_r(p, q) = (p - w)q.$$

Taking the expectation over these two cases, we obtain the following expression for the expected profit of the retailer, as a function of p and q:

$$\begin{aligned}\Pi_r(p, q) &= \mathbb{E}\left[p \min(q, \mathbf{D}(p)) + s(q - \mathbf{D}(p))^+\right] - wq\\ &= s(q + bp) + (p - s)\int_0^{q+bp} \bar{\Phi}(u)du - wq - bp^2.\end{aligned} \tag{3}$$

For a given price p, as the expected profit function is concave with respect to q, we can compute the optimal quantity as a function of p from the first derivative of the expected profit function to q:

$$q^*(p) = \Phi^{-1}(\frac{p - w}{p - s}) - bp. \tag{4}$$

Kocabıyıkoğlu and Popescu (2011) say that without loss of generality, one can focus on prices p greater that a value $\hat{p}_L$, with:

$$\hat{p}_L \geq \arg\max\left\{d\left(p, \Phi^{-1}\left(\frac{p - w}{p - s}\right)\right) : p \geq w\right\},$$

which in our case reduces to:

$$\hat{p}_L \geq \arg\max\left\{\Phi^{-1}\left(\frac{p - w}{p - s}\right) - bp : p \geq w\right\}. \tag{5}$$

Note that the lower bound on $\hat{p}_L$ corresponds to the price greater than the wholesale price w that maximizes the optimal quantity $q^*(p)$ ordered by the retailer. As the expected profit is concave in p ($\frac{\partial^2 \Pi_r}{\partial p^2} < 0$), the optimal price for a given quantity q can be obtained from the first derivative of the expected profit with respect to p:

$$\begin{aligned}\frac{\partial \Pi_r}{\partial p} = &\int_0^{q+bp} \bar{\Phi}(u)du + b(p - s)\bar{\Phi}(q + bp)\\ &+ b(s - 2p) = 0.\end{aligned} \tag{6}$$

Definition 1. The B-LSR (buy-back lost sales rate)elasticity for a given price and order quantity is defined as:

$$\mathcal{E}_s(q, p) = -(p - s)\frac{\frac{\partial \bar{\Phi}(p,q)}{\partial p}}{\bar{\Phi}(p, q)}. \tag{7}$$

As the retailer can return any unsold unit to the supplier and receive its salvage value, the difference between the price and salvage value is the only one subject to a risk from demand uncertainty. Hence we call $p - s$ the *risky part* of price. The buy-back lost sales rate (B-LSR) elasticity is the percentage change in the rate of lost sales with respect to the percentage change in the risky part of price for a given quantity. If there is no salvage value for unsold products, the B-LSR elasticity is equal to the LSR elasticity defined by Kocabıyıkoğlu and Popescu (2011).

$$\mathcal{E}_0 = -p\frac{\frac{\partial\bar{\Phi}(p,q)}{\partial p}}{\bar{\Phi}(p,q)}.$$

Proposition 1. In the linear additive stochastic demand model, if $\mathcal{E}_s \geq \frac{1}{2}$ then $\Pi_r(q,p)$ is jointly concave in p and q.

The condition in Proposition 1 ensures that the Hessian of $\Pi_r(q,p)$ is semidefinite negative for all $q \geq 0$ and $p \geq \hat{P}_L$. As a consequence $\Pi_r(q,p)$ is concave with respect to p or q and we can find a maximum of $\Pi_r(q,p)$ for both p and q.

Proposition 2. If the random variable Z in the demand function has an IFR (increasing failure rate) distribution, there exists a price $\tilde{p}_L$ such that for all $q \geq 0$ and $p \geq \tilde{p}_L$ the Hessian matrix of Π_r is semidefinite negative and there exists q^*, p^* maximizing Π_r.

Proof. We use a method similar to the one of Kocabıyıkoğlu and Popescu (2011) and prove that the profit function is jointly concave in p and q if the determinant of its Hessian matrix is positive :

$$|H| = 2b(p-s)\phi(q+bp) - (\bar{\Phi}(q+bp))^2.$$

Since Z has an IFR distribution, we can show that $|H(p, q^*(p))|$ is an increasing function in p. Recall that we are only interested in values of $p \geq w$, hence from $|H(w, q^*(w))| = -1$ and $\lim_{p\to\infty} |H(p, q^*(p))| \geq 0$ we show that there exists a price $\tilde{p}_L$ ($|H(\tilde{p}_L, q^*(\tilde{p}_L))| = 0$), such that for any price $p \geq \tilde{p}_L$, $|H|$ is positive. Therefore there exists a unique solution (p^*, q^*) on $[\tilde{p}_L, +\infty) \times \mathbb{R}_+$ that maximizes the expected profit.
□

We can introduce a lower bound on p from $\hat{p}_L$ in the equation 5 and $\tilde{p}_L$ defined in Proposition 2 as below:

$$p_L = \max\{\hat{p}_L, \tilde{p}_L : p \geq w\}. \quad (8)$$

Specifically, p_L denotes the minimum price above which one can use the concavity of Π_r to jointly compute an optimal price and quantity. In the next section, we analyze the behavior of the profit function for different sets of parameters with numerical experiments.

4. NUMERICAL ANALYSIS

In this section, we first describe experimental parameters used in numerical solution and solve them through the integration. We consider Z follows a normal distribution (IFR distribution as we required) with known mean, variance ($\mu = 70, \sigma = 10$) and given wholesale price w and salvage value s ($w = 20, s = 50\%w$).

Figure 2 shows the relation of determinant of the Hessian with changing price and for five different values of b, coefficient of the price in the demand function ($0 \leq b \leq 4$). It shows that the Hessian is always increasing function of p, even when b is equal to zero. The effect of b is revealed on the slope of this function (by increasing the value of

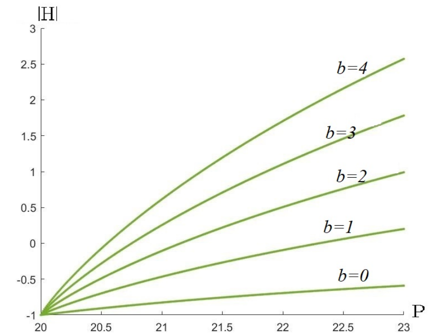

Fig. 2. Hessian with the different coefficients of price

b, the slope of the function increases). The value of the determinant of the Hessian matrix starts from -1 when the price equals the wholesale price ($p = w$) and increases with price p until it becomes positive (except when $b = 0$), so we can spot the price $\tilde{p}_L$ above which the determinant of the Hessian matrix becomes positive.

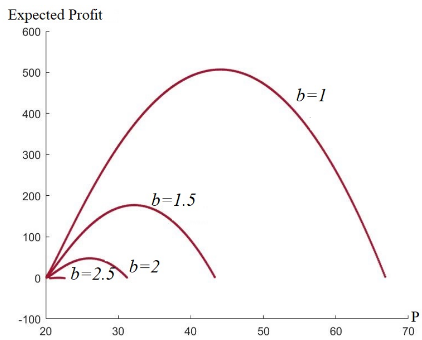

Fig. 3. Expected profit of the retailer

Figure 3 shows how the influence of the price on the demand impacts the expected profit for different values of b ($1 \leq b \leq 2.5$). It shows that there always exists a unique price that maximizes the profit function which decreases when b increases. For large values of b, the negative effect of the price on the demand becomes too prominent for the retailer to make any positive and he does not order any units. It is also worth mentionning that in this additive demand setting that b has a similar impact the lower bound $\tilde{p}_L$, therefore when b increases the range of values of p for which we can jointly optimize p and q widens.

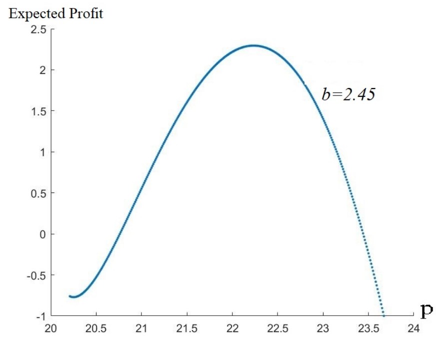

Fig. 4. Expected profit of the retailer b=2.45

Figure 4 illustrates the effect of $\tilde{p}_L$ on the graph of profit function with $b = 2.45$ (close to extreme value of b). It shows for prices close to w the expected profit function is convex, but it becomes concave and has a unique maximum beyond some point $\tilde{p}_L$, as stated in Proposition 2. Similar experiments were also conducted for other IFR distributions, such as Gamma and logistic, and we obtained similar results in all cases.

4.1 Effect of volatility on optimal price and quantity

Our numerical results also confirm what has already been observed by Yao et al. (2008) and stated by Petruzzi and Dada (1999): In the additive demand model, the optimal price decreases as demand uncertainty increases and hence is always less than the one obtained in the deterministic case. For instance, Figure 5 displays the expected profit when Z follows a Logistic distribution for different values of the scale parameter ($0 < sc < 10$), with known mean ($\mu = 60$), fixed wholesale price ($w = 20$) and fixed price coefficient in the demand model ($b = 1.5$). The suggests that increasing volatility leads to the decrease of the optimal price and expected profit. Table 2 shows

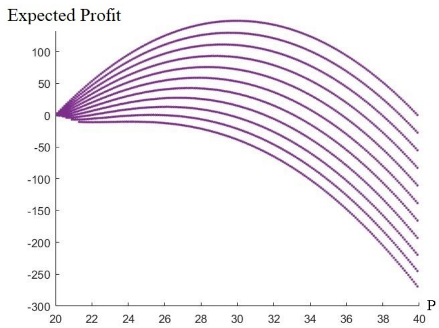

Fig. 5. Expected profit with different sc

the changes in expected profit, optimal quantity, and price when the scale parameter varies. The empirical conclusion is therefore that the volatility of the demand has a negative effect on the profit of the retailer and also decreases his optimal order quantity. As it is mentioned by Petruzzi and

Optimal price	**Expected profit**	**Optimal quantity**	sc
30	148.09	14.93	0.1
29.6	129.24	14.79	1.1
29.2	110.83	14.57	2.1
28.8	92.89	14.25	3.1
28.3	75.46	13.94	4.1
27.8	58.60	13.49	5.1
27.3	42.44	12.90	6.1
26.7	27.14	12.18	7.1
26.1	12.98	11.23	8.1
25.3	0.32	9.96	9.1

Table 2. Effect of scale parameter on optimal price and quantity.

Dada (1999), the optimal price in the stochastic additive demand setting is always lower than its deterministic counterpart. As the volatility decreases, the optimal price increases and get close to the solution of deterministic demand case ($D = a - bp$).

4.2 Effect of salvage value on optimal price

We conduct another numerical experiment, in order to capture the effect of return policies on the optimal price and quantity. We assume that Z is a Logistic distribution with known mean and scale parameter ($\mu = 60, sc = 6$). Wholesale price($w = 20$) and price coefficient in the demand model ($b = 1.5$) are fixed. Figure 6 shows the graph of expected profit for seven different salvage value ($0\%w \leq s \leq 90\%w$). Table 3 shows the effect of the

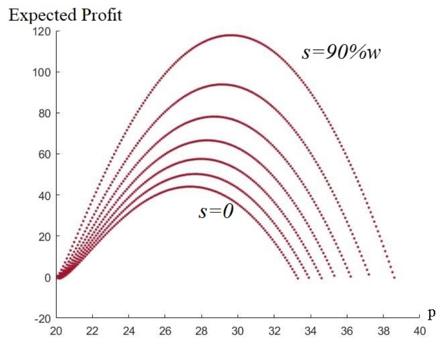

Fig. 6. Expected profit with different s and relatively high volatility

salvage value on the expected profit, optimal quantity and price It is shown that by increasing s, all three parameters also increase. Increasing the salvage value incentivizes the

Optimal price	**Expected profit**	**Optimal quantity**	s
27.4	44.02	12.93	$0\%w$
27.7	55.16	13.70	$15\%w$
28.0	57.52	14.64	$30\%w$
28.3	66.57	15.86	$45\%w$
28.7	78.13	17.45	$60\%w$
29.1	93.79	19.94	$75\%w$
29.6	117.77	25.01	$90\%w$

Table 3. Effect of salvage value on optimal price and quantity.

retailer to order a greater quantity and increase its selling price. In that case, some portion of the uncertainty risk is absorbed by the salvage market, allowing the retailer to adopt a riskier behaviour without facing all its financial consequences. The interesting point in this scenario is that both the optimal price and quantity increase. In particular, a higher price does not lead to a lower ordering quantity from the retailer.

However, the effect of the salvage price on retailer's behavior is mitigated as demand volatility decreases. Figure 7 reveals that for a low scale parameter $sc = 0.1$, changing the salvage value has almost no effect on the retailer's decisions and profit. Table 4 shows the effect of the salvage value on the expected profit, price and quantity when the uncertainty in demand is low. As it is revealed in the numerical experiments, when the volatility of demand is relatively high, the return policies play a crucial role in the expected profit of the retailer, and with a higher salvage value, retailer's optimal price and quantity are higher. In case that the volatility of demand is relatively low, the effect of return policies becomes minor.

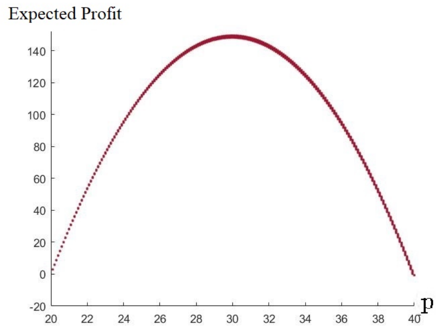

Fig. 7. Expected profit with different s and relatively low volatility ($sc = 0.1$)

Optimal price	**Expected profit**	**Optimal quantity**	s
30.0	148.09	14.93	$0\%w$
30.0	148.22	14.95	$15\%w$
30.0	148.37	14.97	$30\%w$
30.0	148.55	14.99	$45\%w$
30.0	148.76	15.02	$60\%w$
30.0	149.04	15.06	$75\%w$
30.0	149.46	15.16	$90\%w$

Table 4. Effect of salvage value on optimal price and quantity with small volatility.

5. CONCLUSION

In this paper, we focus on the retailer's reaction to the wholesale price contract with return policies in case of price-dependent stochastic demand. First, we analytically show the conditions of retailer's expected profit function concavity for choosing optimal price and quantity simultaneously and examine it numerically. Then we numerically show that benefits of return policies depend on the volatility of demand. In case of relatively stable demand market (low volatility), the effect of the return policies is very mild, and in contrast if the demand volatility is relatively high, return policies are playing a considerable role.

The uncertainty of demand leads to lower profit and in case of additive stochastic demand, it reduces the optimal price and quantity. The management insight is on designing contracts in which the return policies can help mitigate the effect of demand uncertainty. On the market demand with relatively high volatility the retailer's profit function and his decisions can be improved with buy-back policies from the suppliers, but it is not the case when demand market is stable or has low variability.

There are many related areas that need to be further explored. Firstly we have to examine these conditions and relations for a more general demand model, such as multiplicative-additive demand. The relation between the demand variability and return policies can be examined analytically and by introducing the supplier in the model, it can reach to a more general model. The effect of dual channel supply chain is an interesting direction for future investigation on this model, as Li et al. (2017) studied this effect on quantity decision of supply chain. Another interesting area that can be added to the model is financing conditions for the players and information asymmetry about market demand as Wagner (2015) shows the necessity of information asymmetry in stochastic demand system. It illustrates that the market information advantage may not necessarily lead to a higher profit of the firm and even can be the cause of reduction in profit.

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