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VMI for Supply Chains under Demand Expansion Effects

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Abstract

This paper presents a vendor managed inventory (VMI) model for a system with a single vendor responsible for replenishing multiple retailers who face price-dependent demand. In order to boost the demand, the vendor does some advertisement expenditure, while the retailers make sales and marketing effort. A solution procedure is developed in order to determine the game equilibrium. A numerical study is also conducted to understand the influence of various parameters on the performance of different SC members. Results demonstrate that market related parameters have a significant effect on profits. Managerial insights emanating from the study have also been discussed.

Keywords: VMI, pricing, advertising, sales effort, lot-sizing

Vendor Managed Inventory with Demand Expansion Effects

1. Introduction

Any organization controls only a small part of the overall value chain of its products. Thus, enterprises have realized that in order to ensure global optimization, partners in the chain would have to arrive at a shared understanding. With this backdrop, companies across industries are trying to align their supply chains (SC). Coordination and cooperation between companies has been touted as one of the potential sources of sustainable competitive advantage. Indeed, firms like Walmart, Zara, IKEA etc. have successfully leveraged their SC for superior business performance.

Vendor managed inventory (VMI) is one coordination mechanism that has recently been the subject of much academic enquiry. Companies like Barilla, HP, and Shell have benefited by adopting VMI practices. Its adoption across diverse industries has spurred researchers to investigate various facets of VMI adoption. Studies have highlighted that by adopting VMI, companies may be able to reduce the bullwhip effect, as well as enjoy cost benefits. At the same time, it may help in developing more meaningful and mutually rewarding relationships in the SC.

Hines et al. (2000) characterized VMI as a strategy for SC collaboration between a buyer and a vendor within a mutually adopted performance framework that helped in ensuring product availability at a minimal cost. The vendor takes on the responsibility of replenishing the retailer and in the process gains real time access to end level demand information. The former can then use the information for better planning his processes. The retailer may have to make a payment to the vendor for taking care of his inventory and ordering costs.

With the vendor (manufacturer) as a coordinating partner, multiple retailers can become part of a VMI system. The vendor can thus optimize the operations across the entire SC. In this paper, we consider such a system in which the manufacturer acts as the Stackelberg leader and the demand is dependent on the retail price. Additionally, the manufacturer is responsible for national advertising expenditure, which boosts demand. Furthermore, the retailers make sales effort at their individual level for increasing demand which may take the form of information seminars, providing additional services to the customers etc. This may lead to an overall increase in system profits (Boyaci and Gallego, 2004). Such situations are widely seen in practice. For example, consumer product and consumer durable firms advertise their products through various channels. At the same time, the retailers attempt to increase their respective profits by attempting to differentiate themselves through superior customer service, better sales experience etc.

The contributions of this study are threefold. First, we analyze a VMI system in which the SC partners act to increase the demand both at the individual as well as at an overall level. Second, we examine the implications of the VMI service charge charged by the manufacturer from the retailers. Third, we explore the effect of change in parameters of a relatively larger retailer on other SC members, and thus highlight the need for checks and balances in the system. Furthermore, unlike most studies in this field we don't model a 'generic' manufacturer, with a fixed cost of production. His production and inventory policies have been considered to be decision variables in our analysis.

This paper is organized as follows. In section 2, a brief review of relevant literature has been presented. The problem setup and the assumptions involved are discussed in section 3. The formulation of the Stackelberg game with the manufacturer as the leader is presented in section 4. Section 5 contains a numerical example and sensitivity analysis. The implications of the results obtained and managerial insights are discussed in section 6. Section 7 concludes the paper and presents some avenues of future research.

2. Literature review

The literature on VMI is fairly extensive. One stream of research focuses on the adoption of VMI in a SC. Dong et al. (2007) analyzed the environmental determinants of VMI adoption and found that a positive association exists between VMI adoption and the competitiveness of the vendor's market and the extent of buyer–vendor cooperation. Zammori et al. (2009) discussed various components of a standard VMI agreement based on extensive evaluation of such arrangements across a number of companies. Niranjan et al. (2012) developed a tool to assess the suitability of VMI agreement for a given organization. Borade et al. (2013) provided an AHP based framework for evaluation of VMI adoption variables, focusing on the hierarchical linkages between them.

Focusing on the information sharing aspect in VMI, Aviv and Federgruen (1998) found that VMI with information sharing is always more beneficial than VMI alone. Dong et al. (2013) analyzed item-level dataset and concluded that the decision transfer component of a VMI system results in significant benefits for the buyer in terms of savings in inventory and reduction in stockouts. These were over and above the savings due to information sharing alone.

Another stream of literature focuses on the replenishment decisions in a single-vendor multiple-retailers setting. Zavanella and Zanoni (2009) studied a VMI system under consignment with a consecutive delivery policy and analyzed the optimal replenishment decisions in such a setting. Darwish and Odah (2010) considered a VMI system with a contractual storage agreement and under the assumption that all the retailers are replenished in each delivery cycle. Hariga et al. (2013) generalized their model by eliminating the said assumption. Kannan et al. (2013) explored the benefits of VMI in a system where all the parties were part of the same organization.

Game theoretic formulations of VMI systems have been in focus recently. In addition to the optimal inventory policies they also attempt to determine the optimal pricing policy, generally in situations in which the manufacturer is the Stackelberg leader. Yu et al. (2006) were amongst the first to consider such a system. Yu et al. (2009a) studied an extended system incorporating raw material procurement stage in their analysis. Wong (2009) studied the impact of sales rebate in such systems, and found that retailer competition increased vendor profits. Yu et al. (2009b) present a VMI system with localized advertisement by the retailers and determined the optimal pricing, advertising and inventory decisions. Yu and Huang (2010) analyzed how a manufacturer and multiple retailer can optimize the product marketing strategies, platform product configuration and inventory policies under VMI. Almehdawe and Mantin (2010) studied two different situations, first by assuming manufacturer to be the Stackelberg leader and then took one of the retailers as the leader and found that, in general, retailer dominance resulted in higher supply chain efficiency.

Another group of literature focuses on non-price based options of increasing demand. Advertising is a well-recognized option that can significantly increase the demand of products. National advertising by the manufacturer can boost demand and is intended primarily to create favorable product attitude and thus influence end customer purchase intention (Pei and Yan, 2013). Additionally, impact of localized sales and service effort at the retailer is also under active consideration. For example, Ma et al. (2013) analyzed coordination in a two stage SC with demand which is dependent on the retail price as well as quality effort by the manufacturer and marketing effort by the retailer. Similarly, Wu (2012) determined the optimal price and service effort in the SC. Xiao and Xu (2013) studied the impact of service level and pricing in a single vendor, single retailer SC with a fixed retailer order cycle.

There is limited research on the impact of the presence of multiple heterogeneous retailers in a VMI SC (Braide et al., 2013). Govindan (2013), in his review of VMI literature, also highlighted the need to analyze these types of VMI systems. In our paper we make an attempt to fill this gap by focusing on both price effects as well as the role of non-price factors that affect the demand of the products. We present an integrated approach to managing the inventory, pricing, service and advertising decisions in the SC. In this sense, our study attempts to mimic real life situations more closely than existing studies. The insights generated may hence prove to be more actionable.

3. Problem setup

We consider a single product SC consisting of a manufacturer and multiple retailers. All the retailers are operating in distinct markets, i.e. there is no competition between them. As the SC is operating under a VMI system, the manufacturer is responsible for managing the inventory of all the retailers and thus has access to all inventory data. The retailers pay the manufacturer a cost of θ_i per unit consumed (Yu, 2009a; Almehdawe and Mantin, 2010). It is assumed that the production capacity of the manufacturer is large enough to meet the total demand across all the retailers in the system.

The manufacturer can coordinate his production with the demand of the end product as he is responsible for the entire process. It is assumed that all the retailers are replenished in the same replenishment cycle. The manufacturer delivers *n* sub-batches from a given production batch. The notations used are listed below:

S	Set up cost incurred per production batch
T	Common cycle length
P	Production rate for the manufacturer
w	Wholesale price charged by the manufacturer (same for all the retailers)
n	Number of sub batches delivered in a single production batch
A	Advertising expenditure by the manufacturer to boost demand
OC	Operating costs incurred by the manufacturer
NP_m	Net profit for the manufacturer
r	Total number of retailers in the system
NP_i	Net profit got the i^{th} retailer
p_i	Retail price charged by the i^{th} retailer
s_i	Sales effort by the i^{th} retailer
a_i	Order cost corresponding to the i^{th} retailer
θ_i	Per unit payment made by the i^{th} retailer to the manufacturer
α_i	Market scale of the i^{th} retailer
β_i	Price sensitivity of the i^{th} retailer
γ_i	Sales effort coefficient of the i^{th} retailer
δ_i	Advertising effectiveness coefficient of the i^{th} retailer
η_i	Sales effort cost coefficient of the i^{th} retailer
θ_i	Per unit payment by the i^{th} retailer to the manufacturer for managing inventory
$D_i(p_i,s_i,A)$	Demand rate faced by the i^{th} retailer as a function of retail price, sales effort and advertising
D	Total demand rate across all the retailers $\left[=\sum_{i=1}^{r} D_i(p_i,s_i,A)\right]$

3.1 *The demand function*

Price plays a very important role in determining the demand of a product. Linear demand functions have been used extensively in literature (e.g., Lus and Muriel (2009); Sajadieh and Jokar (2009)). In our model, the manufacturer does some national level advertising in order to build brand equity (Xie and Wie, 2009). The benefit of this is enjoyed by each retailer, depending on their respective advertising effectiveness coefficient (δ_i). Additionally, this is supplemented by sales, service and marketing effort at the local level by the retailers themselves. The benefits accrued depend on the sales effort coefficient of each retailer (γ_i). Thus, the demand function for our model can be written as:

$$D_i(p_i,s_i,A)=\left(\alpha_i-\beta_i p_i+\gamma_i s_i+\delta_i\sqrt{A}\right) \tag{1}$$

3.2 *Net profit for each retailer*

The total profit for each retailer can be written as its total revenue (from the sale of the product) minus total costs. The latter would include both the cost price for the product as well as the total payment made by to the manufacturer for managing the inventory. Additionally we also have to consider the cost incurred in the sales and marketing effort. Following Ma (2013), we take this cost to be $\frac{\eta_i s_i^2}{2}$. All other costs would be borne by the manufacturer. Thus, we can write the net profit for the ith retailer as:

$$NP_i = (p_i - w - \theta_i) D_i (p_i, s_i, A) - \frac{\eta_i s_i^2}{2} \tag{2}$$

3.3 *Net profit for the manufacturer*

The total costs incurred by the manufacturer would include the net operating cost (OC) as well as the advertisement expenditure. The former includes the cost of managing the inventory for self as well as all the retailers, ordering cost for all the retailers and the production set up cost production set up cost. Additionally, the manufacturer would also receive payment from the retailers as discussed earlier, which would be charged per unit. Thus, the manufacturer's profit can be written as:

$$NP_m = \sum_{i=1}^{r} \left(w + \theta_i \right) D_i (p_i, s_i, A) - A - OC \tag{3}$$

Next, we will calculate the expression for OC. We have assumed that the production lot is transferred in *n* batches. Since the rate of production is more than the demand rate, the inventory levels at the retailers will increase till the *nth* delivery has been made (Figure 1). After that the next delivery will reach the retailers only when their inventory is finished.

The manufacturer transfers the production lot in 'n' batches of size $Q(=\sum_{i=1}^{r} q_i)$, where q_i is the size of the shipment sent to the i^{th} retailer. Thus, area under the inventory curve of the i^{th} retailer can be written as:

$$= n\left(\frac{1}{2}q_i \frac{q_i}{D_i\left(p_i, s_i, A\right)}\right) + \left(\frac{q_i}{D_i\left(p_i, s_i, A\right)} - \frac{Q}{P}\right) q_i (1 + 2 + 3 + ... + n - 1)$$

We can get the average inventory cost related to all the retailers per year as:

$$= \sum_{i=1}^{r} \frac{D_i\left(p_i, s_i, A\right) h_i}{2}\left[\frac{T}{n} + (n-1)\left(\frac{1}{D} - \frac{1}{P}\right)\frac{DT}{n}\right]$$

The total cost incurred by the manufacturer (OC) can be written as:

$$OC = \frac{S + n\sum_{i=1}^{r} a_i}{T} + \frac{h_v T D^2}{2nP} + \sum_{i=1}^{r} \frac{D_i\left(p_i, s_i, A\right) h_i}{2}\left[\frac{T}{n} + (n-1)\left(\frac{1}{D} - \frac{1}{P}\right)\frac{DT}{n}\right] \qquad (4)$$

Using (4) in (3), we can determine the total net profit for the manufacturer.

4. Stackelberg model

In our VMI system, the manufacturer is responsible for coordinating the decisions for all the partners. The decision variables for the retailers' include the retail price (p_i) and the sales and service effort (s_i). Decision variables for the manufacturer include the wholesale price (w), the number of delivery sub-batches (n), common replenishment cycle (T) and the advertisement expenditure (A).

The manufacturer, as the Stackelberg leader, solves the following optimization problem (S1):

$$\begin{aligned} &Max\ NP_m = \sum_{i=1}^{r} (w+\theta_i) D_i(p_i, s_i, A) - A - OC \\ &n \in I^+ \\ &T, A, w \geq 0 \end{aligned} \tag{S1}$$

The optimization problem faced by each retailer can be formulated as S2:

$$\begin{aligned} &Max\ \ NPi = (p_i - w - \theta_i) D_i(p_i, s_i, A) - \frac{\eta_i s_i^2}{2} \\ &p_i, s_i \geq 0 \\ &i = 1, 2, ..., \mathrm{r} \end{aligned} \tag{S2}$$

The equilibrium point of such games is generally determined through backward induction. Thus, in our case, we first determine the response functions of the retailers corresponding to the manufacturer’s decisions. Then, we solve the decision problem for the manufacturer after incorporating those response functions.

4.1 *Retailers’ best response functions*

We have,

$$NPi = (pi - w - \theta i)\left[\alpha_i - \beta_i p_i + \gamma_i s_i + \delta_i \sqrt{A}\right] - \frac{\eta_i s_i^2}{2} \tag{5}$$

Calculating the first derivative of the profit function of the ith retailer with respect to s_i, we get

$$\frac{\partial NP_i}{\partial s_i} = \left(p_i - w - \theta_i\right)\gamma_i - \eta_i s_i$$

Equating the above to 0, we get the critical value of sales and marketing effort as:

$$s_i^* = \frac{\left(p_i - w - \theta_i\right)\gamma_i}{\eta_i} \tag{6}$$

Using (6) in (5), we get

$$NPi = \left(p_i - w - \theta_i\right)\left[\alpha_i - \beta_i p_i + \frac{\left(p_i - w - \theta_i\right)\gamma_i^2}{\eta_i} + \delta_i\sqrt{A}\right] - \frac{\eta_i}{2}\left[\frac{\left(p_i - w - \theta_i\right)\gamma_i}{\eta_i}\right]^2 \tag{7}$$

Differentiating the above with respect to pi and equating it to 0, we get

$$p_i^* = \frac{\gamma_i^2\left(w + \theta_i\right) - \eta_i\left(\alpha_i + \theta_i\beta_i + w\beta_i + \delta_i\sqrt{A}\right)}{\gamma_i^2 - 2\beta_i\eta_i} \tag{8}$$

Using (8) in (6) and simplifying, we get

$$s_i^* = \frac{\gamma_i\left(\theta_i\beta_i + w\beta_i - \alpha_i - \delta_i\sqrt{A}\right)}{\gamma_i^2 - 2\beta_i\eta_i} \tag{9}$$

Equations (8) and (9) provide the best response functions of the ith retailer.

4.2 *Manufacturer's decision problem*

Incorporating the optimal values of the retail price and the sales effort, we get the modified demand function after simplifying as:

$$D_i(p_i^*, s_i^*, A) = \frac{\eta_i\beta_i\left[\beta_i\left(\theta_i + w\right) - \left(\alpha_i + \delta_i\sqrt{A}\right)\right]}{\gamma_i^2 - 2\beta_i\eta_i} \tag{10}$$

The net profit function for the manufacturer can be written as:

$$\begin{aligned} NPm = \sum_{i=1}^{r}\left(w + \theta i\right)D_i(p_i^*, s_i^*, A) - A - \frac{S + n\sum_{i=1}^{r} a_i}{T} + \frac{h_v T D^2}{2nP} + \\ \sum_{i=1}^{r}\frac{D_i\left(p_i^*, s_i^*, A\right)h_i}{2}\left[\frac{T}{n} + \left(n-1\right)\left(\frac{1}{D} - \frac{1}{P}\right)\frac{DT}{n}\right] \end{aligned} \tag{11}$$

Let,

$$Z = \sum_{i=1}^{r} \frac{D_i\left(p_i^*, s_i^*, A\right) h_i}{2}\left[\frac{1}{n} + (n-1)\left(\frac{1}{D} - \frac{1}{P}\right)\frac{D}{n}\right] \tag{12}$$

Using (12) in (11) and differentiating with respect to T, we get

$$T^* = \sqrt{\frac{2nP\left(S + n\sum_{i=1}^{r} a_i\right)}{2nPZ + h_v D^2}} \tag{13}$$

Using (13) in (4):

$$OC' = \sqrt{\frac{2\left[\left(S + n\sum_{i=1}^{r} a_i\right)\left(2nPZ + h_v D^2\right)\right]}{nP}} \tag{14}$$

Incorporating the values calculated above, the optimization problem faced by the manufacturer can be rewritten as:

$$\begin{aligned} & Max\ NP_m = \sum_{i=1}^{r}\left(w + \theta_i\right) D_i(p_i^*, s_i^*, A) - A - OC' \\ & n \in I^+ \\ & T, A, w \geq 0 \end{aligned} \tag{S1'}$$

For solving the above problem, we can use any optimization software. The profits for the retailers' as well as the optimal values of their decision variables can then be subsequently determined using expressions derived previously.

5. Numerical example and sensitivity analysis

We now present a numerical example of a system with a three retailers who are replenished by a single manufacturer. The data for the system is given in Table 1.

Table 1. Data for the numerical example

$S=450$	$a_1=25$	$h_1=1.75$	$\alpha_1=125$	$\beta_1=1.5$	$\gamma_1=0.45$	$\delta_1=0.80$	$\eta_1=10$	$\theta_1=2.5$
$P=600$	$a_2=25$	$h_2=1.5$	$\alpha_2=100$	$\beta_2=1.2$	$\gamma_2=0.50$	$\delta_2=0.75$	$\eta_2=10$	$\theta_2=2.5$
$h_v=0.75$	$a_3=20$	$h_3=1$	$\alpha_3=250$	$\beta_3=1.75$	$\gamma_3=0.60$	$\delta_3=1$	$\eta_3=12$	$\theta_3=2.5$

We determined the optimal values of the manufacturer's decision variables and his net profit by solving the optimization problem specified by (S1') using LINGO 13. Next, using expressions derived in section 4.1, the decision variables for the retailers' and their respective profits were calculated. In order to gain some insights regarding the performance of the system, we conducted detailed sensitivity analysis as discussed below. This was done for both production related parameters (holding, setup and ordering costs), as well as market related parameters (market scale, advertising effectiveness coefficient, sales and marketing effort coefficient etc.).

5.1 *Impact of change in production related parameters*

We observed that the effect of changes in these parameters was primarily observed for the replenishment variables (i.e. how often the manufacturer delivers the product to the retailers). Other variables like the retail price, wholesale price, advertising expenditure etc. remained largely unchanged. These observations were in line with the findings in existing studies like Yu (2006) and Yu (2009b). Hence, in the remaining part of the paper, we focus on the effect of change in market related parameters.

5.2 *Impact of change in market related parameters*

Next, we investigated the effect of change in the market related parameters on the system. In this analysis, we specifically focused on the parameter values of retailer 3, as it was the retailer with the largest market scale factor and would thus arguably have the biggest impact on system performance. It enabled us to analyze the effect of changes in the parameters of the strongest retailer on the other not-so-strong retailers also present in the system. In the ensuing analysis we have used the notation Rk (k=1, 2, 3) to refer to the k^{th} retailer.

5.2.1 *Change in market scale of R3 (α_3)*

An increase in market scale indicates a larger market potential for R3. It increased his demand and at the same time he was able to charge a higher retail price, as the price sensitivity remained fixed. Correspondingly, his profits increased. The manufacturer, who was the leader in the SC, also wanted to extract a larger share of the system profits. The primary tool available to him is the wholesale price. He increased *w* and thereby his own profits. In order to increase his profits even further, he also increased his advertising expenditure. While the latter would boost the demand for all the retailers, the increase in *w* actually reduced the profits for R1 and R2. Given their relatively smaller market scale, they attempted to cope with that increase by increasing their respective retail prices, yet this led to a decrease in the demand. Consequently, both of them ended up suffering in terms of their respective profits. The impact of change in α_3 on the prices charged and profits made is shown in Table 2.

Table 2. Impact of change in α_3

α_3	A	w	p_1	p_2	p_3	NP_1	NP_2	NP_3	NP_m
150	1057.6	49.84	76.67	78.27	78.54	882.31	798.54	1191.48	4464.81
200	1367.4	56.70	81.27	83.07	97.64	726.27	676.79	2563.65	5839.44
225	1537.1	60.13	83.58	85.47	107.18	653.88	619.64	3444.37	6592.07
250	1716.6	63.56	85.88	87.87	116.73	585.27	564.99	4454.82	7388.24
275	1906.1	66.99	88.18	90.27	126.28	520.44	512.84	5594.97	8227.94
350	2533.5	77.29	95.09	97.47	154.92	348.67	371.44	9793.44	11008.16

5.2.2 *Change in price sensitivity of R3 (β_3)*

An increase in price sensitivity indicates that the demand for the product would go down by a larger amount per unit increase in the retail price. We found that an increase in β_3 was accompanied by a decrease in the retail price charged by R3 as well as a decrease in the demand satisfied by him. The manufacturer, in keeping with the shrinking market (note that R3 is the major retailer in the system), also decreased his advertising expenditure. He was also forced to lower *w*as a result of change in price sensitivity. Retailers R1 and R2 emerged as the beneficiaries in this scenario, as they were able to get better margins (even while charging lower prices) as well as cater to a higher level of demand due to the reduction in *w*. Furthermore, they also increased their sales and marketing effort in order to maximize their respective earnings. As shown in Table 3, the net profits for the manufacturer and R3 went down substantially, while R1 and R2 enjoyed much larger profits.

Table 3. Impact of change in β_3

β_3	A	w	p_1	p_2	p_3	NP_1	NP_2	NP_3	NP_m
1.2	2410.0	75.36	93.79	96.13	164.63	378.41	396.37	8923.56	8820.81
1.6	1872.2	66.39	87.78	89.85	126.64	531.37	521.66	5284.37	7731.47
1.75	1716.6	63.56	85.88	87.87	116.73	585.27	564.99	4454.82	7388.24
2	1497.4	59.33	83.04	84.91	103.40	670.59	632.91	3430.61	6877.29
2.5	1168.4	52.33	78.36	80.03	84.43	824.55	753.85	2177.05	6034.58
3	936.6	46.78	74.64	76.15	71.52	958.22	857.50	1476.45	5367.16

5.2.3 *Change in per unit payment (θ_3)*

An increase in this payment indicates that the manufacturer is charging more for providing his services (managing inventory and ordering) to the retailers. Change in θ_3 did not affect the retail prices and demand serviced by R1 and R2 in a big way, and consequently their profits remained stable. The advertising expenditure also remained relatively unchanged. R3's net profit went down and manufacturer's net profit went up. The impact of change in θ_3 on the wholesale and retail prices and profits of the retailers and the manufacturer is shown in Table 4.

Table 4. Impact of change in θ_3

θ_3	A	w	p_1	p_2	p_3	NP_1	NP_2	NP_3	NP_m
1.75	1716.6	63.85	86.02	88.02	116.50	576.52	557.28	4495.20	7364.37
2	1716.6	63.76	85.98	87.97	116.58	579.43	559.85	4481.72	7372.39
2.25	1716.6	63.66	85.93	87.92	116.65	582.35	562.42	4468.26	7380.35
2.5	1716.6	63.56	85.88	87.87	116.73	585.27	564.99	4454.82	7388.24
2.75	1716.6	63.46	85.83	87.82	116.80	588.21	567.57	4441.40	7396.06
3	1716.6	63.36	85.78	87.77	116.88	591.15	570.16	4428.00	7403.81
5	1716.6	62.57	85.39	87.38	117.48	614.94	591.08	4321.52	7463.44

5.2.4 *Change in advertising effectiveness coefficient (δ_3)*

Higher value of δ_3 implies that for the same advertising expenditure, R3 would be able to service a larger demand. Thus, the manufacturer would be inclined to increase the expenditure on advertisements, so as to derive more benefit. Moreover, with an increase in demand, it was found that the retail price charged by R3 (as well as R1 and R2) also increased. The retailers' also increased their respective sales efforts in order to take advantage of the increase in retail prices. In order to wrest a larger share of the system profits, the manufacturer increased *w*. The impact of change in δ_3 on the prices charged and profits made is shown in Table 5.

Increase in *A* would benefit all the retailers. However, contrary to expectations, the net profit increase for R1 was found to be lower than that for R2, even though $\delta_1 > \delta_2$. This must be understood in terms of the nature of the system. Net profit for all the members are dependent on the multitude of trade-offs involved. Thus, the increase in demand due to an increase in *A* might be more than offset by the accompanying increase in the wholesale price.

Table 5. Impact of change in δ_3

δ_3	**A**	**w**	p_1	p_2	p_3	NP_1	NP_2	NP_3	NP_m
0.5	946.1	58.80	80.65	82.15	106.87	557.70	515.93	3601.52	6822.83
0.6	1070.7	59.62	81.58	83.17	108.49	564.48	526.31	3731.59	6919.63
0.7	1208.5	60.50	82.57	84.25	110.28	570.66	536.41	3879.84	7023.99
0.8	1360.8	61.44	83.61	85.39	112.25	576.21	546.24	4048.20	7136.45
1	1716.6	63.56	85.88	87.87	116.73	585.27	564.99	4454.82	7388.24

5.2.5 *Change in sales effort coefficient (γ_3) and sales effort cost coefficient (η_3)*

The effect of changes in these two parameters remained largely localized, affecting only R3 and the manufacturer. Increase in γ_3 implied that it became relatively more attractive for R3 to increase his sales effort, as he could garner larger profits for the same effort. Increase in the demand serviced also enabled R3 to charge a little extra per unit of product sold (Table 6). As usual, the manufacturer was also able to increase *w*, in order to maximize his profits. There was no uniform effect on R1 and R2 as their profits were dependent on their respective optimization problems.

The impact of an increase in η_3 was opposite to that of γ_3. R3 decreased his sales effort, and the manufacturer also decreased *w*, in order to shore up the demand. As before, the effect of this change on the profits of R1 and R2 was not the same.

Table 6. Impact of change in γ_3

γ_3	w	p_1	p_2	p_3	s_1	s_2	s_3	NP_1	NP_2	NP_3	NP_m
0.3	63.47	85.79	87.77	116.31	0.89	1.09	1.26	585.36	564.67	4425.81	7351.20
0.45	63.50	85.83	87.81	116.48	0.89	1.09	1.89	585.32	564.80	4437.85	7366.57
0.55	63.54	85.86	87.85	116.64	0.89	1.09	2.32	585.29	564.92	4448.61	7380.31
0.6	63.56	85.88	87.87	116.73	0.89	1.09	2.53	585.27	564.99	4454.82	7388.24
0.75	63.63	85.95	87.94	117.05	0.89	1.09	3.18	585.22	565.25	4476.85	7416.37
1	63.78	86.10	88.11	117.75	0.89	1.09	4.29	585.11	565.81	4525.24	7478.20
1.25	63.98	86.29	88.32	118.67	0.89	1.09	5.44	585.00	566.60	4589.13	7559.89

6. Concluding remarks

In this paper we developed a model for a single product VMI system with a single manufacturer and multiple retailers. Retailers could supplement their demand through sales effort at the local level while the manufacturer assumed responsibility for national level advertising. The latter was assumed to be the Stackelberg leader and the optimization problem was solved for the manufacturer as well as the retailers. Managerial insights were derived from a numerical study.

Changes in market related parameters had a significant influence on the performance of the system. For example, increase in market scale improved the profit generated by the VMI system. It was also observed that the pricing decisions were less sensitive to changes in production related parameters. However, changes in these parameters could significantly influence the inventory policy.

We also discussed the managerial implications of the study. Specifically, we discussed the impact of coupling together asymmetric parties into a common system, effect of the presence of a relatively stronger retailer and the issue of retailer specific wholesale price strategy.

Multiple avenues can be explored to add to the contributions of this study. The change in system performance pre and post VMI implementation may be explored. Furthermore, mechanisms to arrive at a jointly acceptable VMI service charge must also be analyzed. Systems with more than two stages as well as the role of capacity constraint at different stages can also be studied. Lastly, it may also be useful to study the change in system dynamics due to competition between the retailers.

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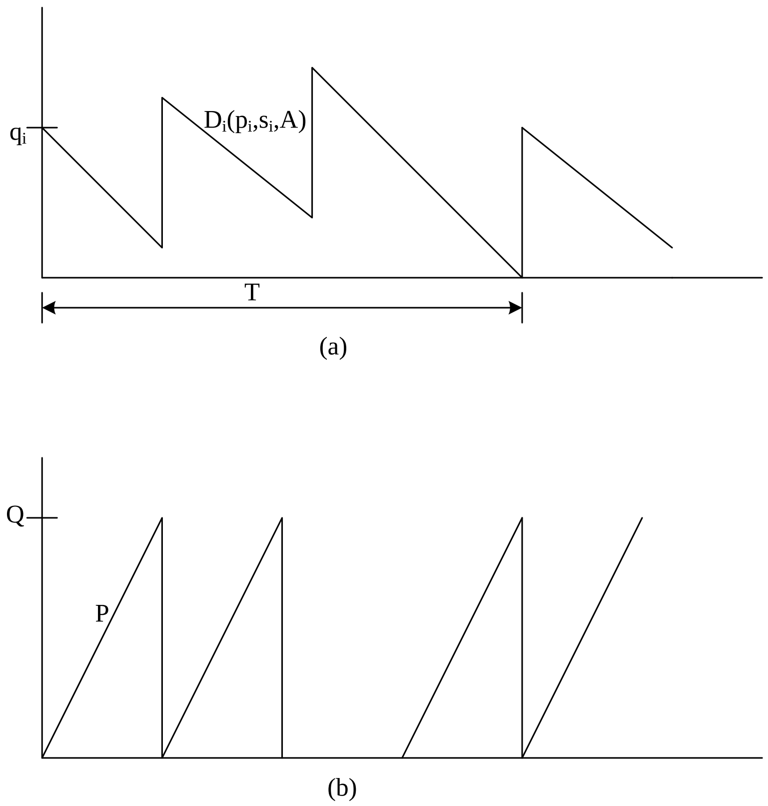

Figure 1. Stock level vs. time with n=3 for (a) Retailer *i* , and (b) Manufacturer

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