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Analysis of production-inventory decisions in a decentralized supply chain with price-dependent demand

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Abstract. In this paper, we consider a production-inventory supply chain system with single-manufacturer and single-retailer. There are many types of contract that guarantee the supply chain. However, the administrative costs of the contract are usually neglected in real situation. The additional gain from integration may not cover the extra administrative costs may not addressed to supply chain. Therefore, a Stackelberg game and RFM policy are examined in order to investigate its performance on supply chain. The RFM policy is applied because its administrative costs are lower than othe policies. Although RFM policy is not capable of coordinating the channel, it leads to considerable improvements over the channel. The purpose of this research is to present a model of integrated policy, in which the goal is to maximize the whole system profit, and to evaluate decentralized-Stackelberg and RFM policies, in which individual firms in the supply chain have their own objectives and decisions to optimize.

1. Introduction

Generally, a supply chain is composed of independent members, each with its own individual costs and objectives. It is important how the members behave to manage their inventory. The integrated policy should be chosen when the take care about overall system performance. However, each member may be interested in maximing its own profit independently. In this case, the whole channel's performance could not necessarily be optimzed, *i.e.* the decentralized policy. Therefore, the overall system performance may be improved by using a collaboration mechanism. Note that the channel will be collaborated under one contract if i) channel's profit reaches its maximum as in integrated policy; and, ii) none of the members' profit is worse compared with the decentralized policy. There is extensive research on the channel cooperation problem by means of designing efficient contracts, such as revenue sharing contracts, buyback contract, and cost sharing. The supply chain incurs some extra administrative costs by applying those contracts. The additional gain from coordination mat not cover the costs. Alaei et al. [1] considered the production-inventory problem in a two level supply chain which is formulated as a Stackelberg game. They examined the retail fixed mark-up (RFM) in order to investigated its performance on supply chain. In the Stackelberg approach, two firms play a game to obtain Stackelberg equilibrium. The equilibrium is a pair of policies in which each firm maximizes its own profit assuming the other player sets his equilibrium policy. Furthermore, in RFM policy, the manufacturer determines the wholesale price first, that is equivalent to setting the retail price. In this policy, only the retail price must be monitored. Thus, the administrative costs related to this type of contract are lower than those of other contracts. In many industries fixed mark-ups are used such as electronics industry, gasoline dealers, and grocers. Moreover, RFM is also investigated in marketing environent. Li and Atkins [8] consider RFM policy for operation sections and marketing in a single firm. Liou et al. [10] proposed multy-period inventory models. They studied the problem under the Stackelberg approach to achieve the optimal policies. Furthermore, several mult-echelon inventory systems are analyzed by using Stackelberg game.

Many integrated manufacturer-retailer inventory models assumed that the demand rate is constant and is not affected by the retail price of the product. It means that the demand remains the same over the changing of the retail price. Rad and Khoshalhan [11] proposed the integrated inventory model with backorder and assumed that the demand rate is constant. Shah et al. [13] developed the integrated inventory model with the influence of availability of stock goods under the constant demand rate. However, according to Within [14], retail price is one of the important decision variable which influences. Within [14] developed the economic order quantity (EOQ) model with pricing for a buyer that has a price dependent demand with a linear function. Many researchers are encouraged by his work to investigate joint ordering and pricing problems. The focus of these models has been on demand functions (e.g., Lau and Lau [7]), on quantity discount (e.g., Lin and Ho [9]), or on perishable inventories (e.g., Khanra et al. [5]). Chung and Wee [3] proposed joint ordering and pricing problemsin which multiples companies in a supply chain coordinate with each other. Kim et al [6] developed a supply chain consisting of a single manufacturer and a single retailer under joint ordering and pricing policies for price-dependent demand. Chung and Liao [2] also introduced the integrated inventory model that involve price-sensitive demands. Recently, Rad et al. [12] discussed the integrated inventory model that considers operations and pricing decisions, where the demand rate has an iso-elastic function of the selling price.

To the best of knowledge, none of the above-mentioned decentralized models focused on the effects of decentalized policies on the performance of the supply chain comparing to integrated production-inventory models, especially when the demand rate has an iso-elastic function of the selling price. Therefore, in this paper, we consider a supply chain with a single manufacturer and a single retailer in a production-inventory system. An outside supplier supplies raw material to the vendor with zero lead time, and the vendor produces a product, and supplies it to a buyer who in turn supplies it to the consumers. Furthermore, it is assumed that the buyer faces price-dependent demand. End customer demand is assumed to be an iso-elastic function of the selling price to account for the impact of price changes on customer demand. The buyer uses EOQ inventory policy for controlling his costs. The vendor operates on a make-to-order basis and uses a lot-for-lot policy. The research conducted in this paper presents a model of (1) integrated policy, in which the goal is to maximize the whole system profit, and (2) to evaluate decentralized-Stackelberg and decentralized-RFM (Retail Fixed Mark-up) policy, in which individual firms in the supply chain have their own objectives and decisions to optimize.

2. Notations and Assumptions

To develop the proposed model, the following notations and assumptions are introduced.

2.1. Notations

A : Retailer fixed ordering cost
S : Manufacturer fixed setup cost
h : Retailer unit holding cost *per* unit time
H : Manufacturer unit holding cost *per* unit time
T : Cycle time
D : Price-dependent annual market demand
p : Retail price *per* unit (decision variable), $p > 0$
w : Wholesale price *per* unit (decision variable), $c < w < p$
c : Procurement cost *per* unit, $0 < c < w$
k_1 : Time-dependent production cost *per* unit time
k_2 : Technology development cost, *per* one unit increasing on the production rate
l : Lead time

μ : Manufacturer production rate
Q : Order Quantity (decision variable)
TP_r : Retailer profit
TP_m : Manufacturer profit
JTP : The joint total profit

2.2. Assumptions

1. There are single-manufacturer and single-retailer for a single product in this model.
2. Shortage is not allowed.
3. For each unit of product, the manufacturer spends c in production and receives w from retailer. After that, the retailer sell it by p to its customer. The relationship between them is $p > w > c$.
4. The demand rate is a decreasing function of the retail price, $D(p) = \gamma p^{-\beta}$, where $\gamma > 0$ is a scaling factor and $\beta > 1$ is the index of price elasticity. This type of demand function, which has been used by researchers such as Hays and DeLurgio (2009), Lin and Ho [4] and Rad *et al.* [6], for example, is commonly referred to as iso-elastic demand function. For notational simplicity, $D(p)$ and D will be used interchangeably in this article.

3. Model Formulation

In this section, the retailer's and the manufacturer's inventory model are derived.

3.1. Retailer's total profit

We assume that the retailer uses the EOQ inventory policy as shown in Figure 1 for controlling his costs. The retailer's total profit includes the profit of the products, average ordering cost, and average holding cost. Thus the total annual profit of the retailer is given by

$$TP_r(p,Q) = \text{sales revenue of retailer – ordering cost – purchasing cost – holding cost}$$
$$= \left(\gamma p^{-\beta}\right)\left(p - \frac{A}{Q} - w\right) - \frac{hQ}{2}. \quad (1)$$

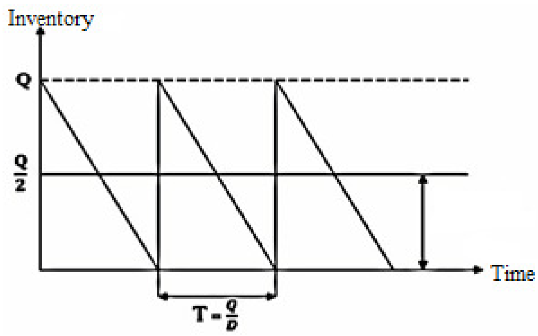


Figure 1. Retailer's inventory level

3.2. Manufacturer's Total Profit.

The manufacturer's inventory level is shown in Figure 2. The manufacturer's total profit consists of sales revenue, holding cost, setup cost, and time-dependent production cost. The setup cost is divided into two parts: one part is fixed for every production period, and another one is an increasing function of the production rate. For instance, assume an assembly line that has the technology for assembling a set of parts that are supplied by a supplier. In this assembly line, time-dependent production cost coincides with the daily production cost. It is necessary to enhance the technology when the production rate exceeds a specific limit. Therefore, it is assumed that the manufacturer incurred a cost called technology development cost for every increasing unit on the production rate. For example, if the manufacturer incurred \$400 for increasing 200 units on the production rate, then the unit technology development cost will be \$2.

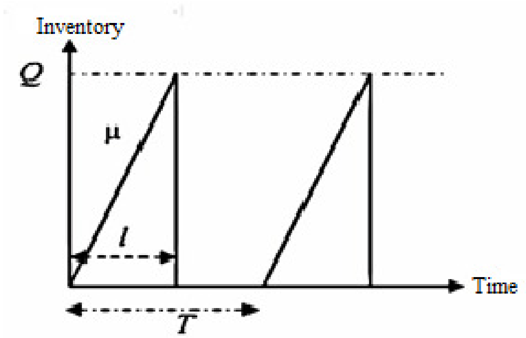


Figure 2. Manufacturer's inventory level

The manufacturer operates on a make-to-order basis using a lot for-lot policy, hence, the manufacturer begins to produce a batch of Q at the rate of μ, as soon as he receives an order and delivers it to the retailer after the lead time. It is assumed that the manufacturer has to produce the product with minimum possible production rate during the lead time, so we have $\mu = Q/l$. Thus, the total annual profit of the manufacturer can be expressed by

$$\begin{aligned} TP_m(p,Q) &= \text{sales revenue of manufacturer} - \text{setup cost} \\ &\quad - \text{time-dependent production cost} - \text{holding cost} \\ &= \left(\gamma p^{-\beta}\right)\left(w - c - \frac{S}{Q} - \frac{k_1 l}{Q} - \frac{k_2}{l} - \frac{Hl}{2}\right). \end{aligned} \tag{2}$$

4. Policies

4.1. Integrated Policy

In this policy, the goal is maximizing the joint total profit (JTP) which is the sum of the total annual profit for retailer (TP_r) and manufacturer (TP_m). Then the problem to be solved is to maximize

$$JTP(p,Q) = \left(\gamma p^{-\beta}\right)\left(p - c - \frac{(S+A+k_1\, l)}{Q} - \frac{Hl}{2} - \frac{k_2}{l}\right) - \frac{h\,Q}{2}. \tag{3}$$

Where retail price (p) and order quantity (Q) are decision variables.

Proposition 1. *The integrated order quantity Q^* is one of the positive roots of the following equation:*

$$h(Q)^2 - 2^{1+\beta}\gamma(S + A + k_1 l)\left(\frac{\beta\left(2l(S+A+k_1 l)+2k_2 Q+lQ(2c+Hl)\right)}{lQ(\beta-1)}\right)^{-\beta} = 0. \tag{4}$$

And, the integrated retail price is

$$p^* = \frac{\beta\left(c + \frac{(S+A+k_1 l)}{Q^*} + \frac{H\,l}{2} + \frac{k_2}{l}\right)}{\beta - 1}.$$

Proof. The optimal retail price, p^*, is obtained from $\frac{\partial JTP(p,Q)}{\partial p} = 0$. Similarly, from $\frac{\partial JTP(p,Q)}{\partial Q} = 0$, the optimal order quantity is $Q^* = \frac{\sqrt{2\gamma p^{-\beta}(S+A+k_1\, l)}}{\sqrt{h}}$, and Equation (4) can be achieved by simultaneously considering p^* and Q^*. It can be proved that this form of equations either has two positive roots or have no one. Furthermore, the Hessian matrix of $JTP(p,Q)$ is

$$\mathbf{H} = \begin{pmatrix} \frac{\partial^2 JTP(p,Q)}{\partial p^2} & \frac{\partial^2 JTP(p,Q)}{\partial p \partial Q} \\ \frac{\partial^2 JTP(p,Q)}{\partial Q \partial p} & \frac{\partial^2 JTP(p,Q)}{\partial Q^2} \end{pmatrix},$$

where

$$\frac{\partial^2 JTP(p,Q)}{\partial p^2} = -\frac{1}{2lQ}p^{-2-\beta}\gamma\beta(2l(S+A+k_1l)+2k_2Q+l(2c+Hl+2p)Q+(2l(S+A+k_1l)+2k_2Q+l(2c+Hl+2p)Q)\beta),$$
$$\frac{\partial^2 JTP(p,Q)}{\partial p\partial Q} = \frac{\partial^2 JTP(p,Q)}{\partial Q\partial p} = -\frac{\gamma\beta p^{-\beta-1}(S+A+k_1l)}{Q^2},$$
$$\frac{\partial^2 JTP(p,Q)}{\partial Q^2} = -\frac{2\gamma p^{-\beta}(S+A+k_1l)}{Q^3}.$$

Checking the sign of the first and second principal minor determinant of **H**, we get

$$|H_{11}| = \frac{\partial^2 JTP(p,Q)}{\partial p^2} < 0$$
$$|H_{22}| = \frac{1}{lQ^4}(S+A+k_1l)p^{-2(1+\beta)}\beta\gamma^2\big(2l(S+A+k_1l)+2k_2Q+l(2c+Hl+2p)Q+\big(2k_2Q+l(S+A+k_1l+2cQ+HlQ-2pQ)\big)\beta\big) > 0.$$

Therefore, the Hessian matrix is a negative definite matrix, so $JTP(p,Q)$ is a concave function in p and Q. Therefore, (p^*,Q^*) maximizes the integrated inventory model.

4.2. Decentralized (Stackelberg policy)

In Stackelberg policy, manufacturer and retailer are classified as leader and follower, respectively. The manufacturer chooses a strategy first, and then the retailer observes this decision and makes his own strategy. It is necessary to assume that each enterprise is not willing to deviate from maximizing his profit. In other words, each player chooses his best strategy. The manufacturer determines his wholesale price, and acts as a leader by announcing it to the retailer in advance, and the retailer acts as a follower by choosing his retail price and order quantity based on the manufacturer's strategy.

Proposition 2. *The Stackelberg's order quantity and wholesale price are achieved by solving the following system of equations:*

(i) $h\,(Q^*)^2 - 2\,A\,\gamma\left(\frac{(A+Q^*\,w)\beta}{Q^*(\beta-1)}\right)^{-\beta} = 0$, *and* (5)

(ii) $\frac{\left(\frac{(A+Q^*\,w^*)p}{Q^*(\beta-1)}\right)^{-\beta}\left(2l\,(A+Q^*\,w^*)\gamma+\left(2k_2Q^*+l\left(2S+2k_1l+Q^*(2c+Hl-2w^*)\right)\right)\gamma\beta\right)}{2l\,(A+Q^*\,w^*)} = 0,$ (6)

and the Stackelberg's retail price is

$$p^* = \frac{A\beta+Q^*\,w\beta}{Q^*(\beta-1)}.$$

Proof. We need the retailer's reaction function (p^*,Q^*) for given w. It can be proved that the Hessian matrix of TP_r is a negative definite matrix, so TP_r is concave in p and Q. Therefore, the optimal retail price and the optimal order quantity are obtained from $\frac{\partial TP_r(p,Q)}{\partial p} = 0$ and $\frac{\partial TP_r(p,Q)}{\partial Q} = 0$. We get

$$p = \frac{A\beta+Qw\beta}{Q(\beta-1)} \tag{7}$$

and

$$Q = \sqrt{\frac{2A\gamma p^{-\beta}}{h}}. \tag{8}$$

By simultaneously considering equations (7) and (8), we obtain Equation (5). Further, by substituting p to the manufacture's total profit, we have

$$TP_m = \left(\gamma\left(\frac{A\beta+Qw\beta}{Q(\beta-1)}\right)^{-\beta}\right)\left(w-c-\frac{S}{Q}-\frac{k_1l}{Q}-\frac{k_2}{l}-\frac{Hl}{2}\right). \tag{9}$$

The optimal wholesale price is achieved by maximizing Equation (9) with respect to w or equivalently $\frac{\partial TP_m}{\partial w} = 0$. Then we get Equation (6).

4.3. Decentralized (RFM policy)

In RFM policy, the wholesale price is determined first by the manufacturer. Next the retailer sets his order quantity. The retailer receives a fixed mark-up ($\alpha = 1 - w/p$). Hence, setting the wholesale price by manufacturer is equivalent to choosing the retail price. Then, the retailer only chooses on value of order quantity and the manufacturer decides the retail price. Note that, the value of α is assumed to be exogenously given, and, not to be endogenously determined. It is important to specify that for which values of α, the RFM policy will be desirable for both members. By substituting $w = (1 - \alpha)p$ to equations (1) and (2), we obtain the total profits of two firms under RFM as below:

$$TP_r(p, Q) = \left(\gamma\, p^{-\beta}\right) \left(\alpha p - \frac{A}{Q}\right) - \frac{hQ}{2} \tag{10}$$

and

$$TP_m(p, Q) = \left(\gamma\, p^{-\beta}\right) \left(p - \alpha p - c - \frac{S}{Q} - \frac{Hl}{2} - \frac{k_1 l}{Q} - \frac{k_2}{l}\right). \tag{11}$$

Proposition 3. *RFM's order quantity and retail price are achieved by solving the following system of equations:*

(i) $\frac{h\,(Q)^2}{2\,A} - \gamma\,(p)^{-\beta} = 0, and$ (12)

(ii) $p^{-1-\beta}\gamma\left(2k_2 Q\beta + l^2(2k_1 + HQ)\beta + 2l\big((S + cQ)\beta + pQ(\beta - 1)(\alpha - 1)\big)\right) = 0.$ (13)

Proof. Similar to previous section, the retailer's reaction, Q, is obtained from $\frac{\partial TP_r(p,Q)}{\partial Q} = 0$. We have

$$Q = \sqrt{\frac{2A\gamma p^{-\beta}}{h}}.$$

The manufacturer maximizes his total profit by taking the retailer's reaction into account. Furthermore, simplifying $\frac{\partial TP_m(p,Q)}{\partial p} = 0$ results the Equation (13). Moreover, it can be proved that the profit function is concave.

5. Numerical example

Numerical examples given below are for illustrating the feasibility of the above policies. Moreover, the Pareto-improvement region through a numerical study is illustrated. Next, a sensitivity analysis is performed by changing the values of major parameters. We consider the retailer's and the manufacturer's inventory systems with the following data: $D(p) = 300000\, p^{-1{,}25}$ units per year, $A =$ \$80 per order, $c =$ \$13 per unit, $S =$ \$300, $k_1 =$ \$1000, $k_2 =$ \$0.0002, $l = 0.02$, $h =$ \$1.2, $H =$ \$1. In RFM, we assume that α is equal to 0.32.

Table 1. Solutions of integrated policy, Stackelberg policy and RFM policy.

	Q^*	w^*	p^*	TP_r	TP_m	*JTP(p,Q)*
Integrated policy	1021	-	67.059	-	-	83256
Stackelberg policy	152	77.768	391.479	53865	10792	64657
RFM policy	351	69.667	102.452	29754	51297	81051

The solutions of integrated policy, Stackelberg policy and RFM policy are summarized in Table 1. The table shows that the manufacturer's profit is higher in RFM policy comparing to Stackelberg policy. The opposite results occurs in retailer's profit. However, we can see that RFM profit is higher than Stackelberg profit. Furthermore, we define the competition penalty (ρ) as the difference between the integrated profit and Stackelberg/RFM profit measured as a fraction of the integrated profit. For RFM policy, this value is equal to 3% but increased to 23% in Stackelberg policy. It is important to determine an interval ($\alpha_{min}, \alpha_{max}$) in which both retailer and manufacturer can benefit from RFM policy.

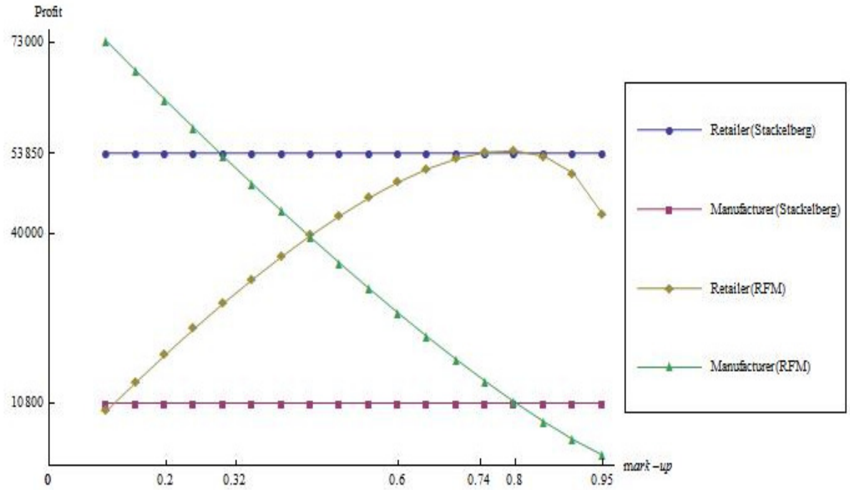
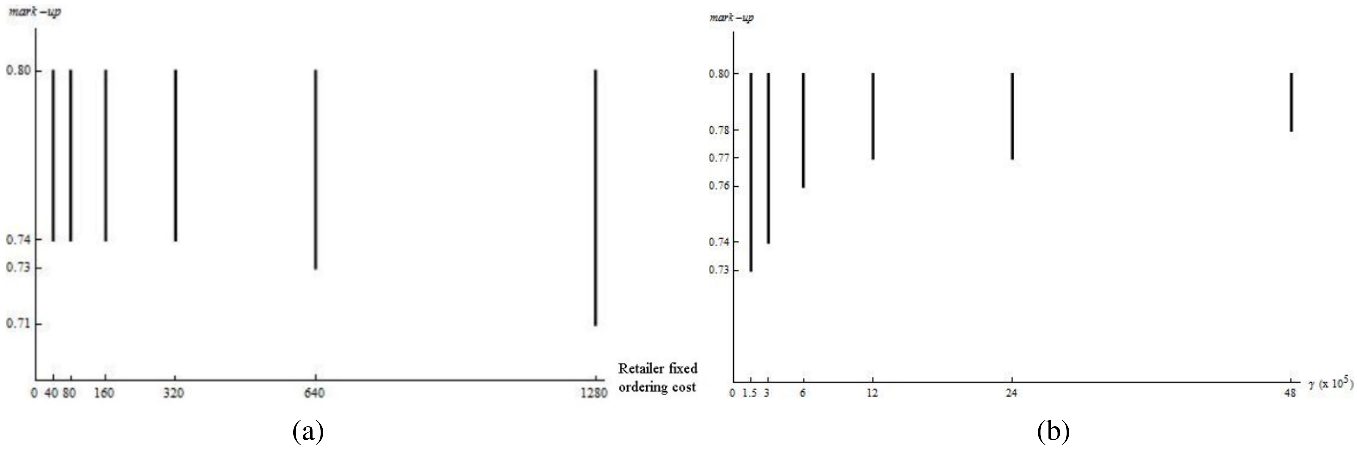


Figure 3. Variations of profit functions respect to α.

Figure 3 shows the manufacturer's and retailer's profit functions with respect to α under the Stackelberg and RFM policies. It can be seen that the retailer's profit function is concave and has a maximum value. However, the manufacturer's profit function is convex and decreasing in α. There exists a α_{max} such that if $\alpha \leq \alpha_{max} = 0.83$, the manufacturer can benefit from RFM policy comparing to Stackelberg policy. Similarly, there exist α_{min} and α_{max} such that if $0.74 = \alpha_{min} \leq \alpha \leq \alpha_{max} = 0.83$, the retailer can benefit from RFM policy comparing to Stackelberg policy. Furthermore, we can see that in the interval $(\alpha_{min}, \alpha_{max}) = (0.74,\ 0.83)$, both the manufacturer and the retailer will always prefer RFM policy to stackelberg policy. The interval $(0.74,\ 0.83)$ is a Pareto efficient strategy for the given data. Next, we investigate this Pareto-improving region numerically. The variation of this region with respect to retailer fixed ordering cost, A, and scaling factor of demand rate, γ, is illustrated in Figure 4. From the figure, the higher the ordering cost, the longer the interval of Pareto efficient strategy. However, the opposite results occurs in the scaling factor of demand rate.



(a) (b)

Figure 4. Pareto-improving region in (a) retailer fixed ordering cost and (b) scaling factor of demand rate.

6. Sensitivity Analysis

The sensitivity analysis is performed by changing the values of major parameters. Table 2 illustrates the sensitivity analysis of the parameters and the competition penalty (ρ) for RFM policy with three different retail fixed mark-up rates. In the table, Δ_r is defined as the retailer's percentage improvement of RFM policy comparing to Stackelberg policy. Similarly, Δ_m is defined for the retailer's. Negative values shows that the retailer's/manufacturer's profit in RFM policy is lower than that of Stackelberg's. The RFM is not a Pareto efficient strategy if either Δ_r or Δ_m is negative. Moreover, the variations of decision variables for integrated, Stackelberg, and RFM policies with three different retail fixed mark-up rate are illustrated in Table 3.

Table 2. Two approach solutions under variation of major parameters

Solutions→		Stackelberg	RFM (0.74)			RFM (0.76)			RFM (0.78)		
Paramaters ↓		ρ	ρ	Δ_m	Δ_r	ρ	Δ_m	Δ_r	ρ	Δ_m	Δ_r
c	7	23	17	41.489	0.369	19	27.775	0.862	21	14.318	1.079
	18	22	17	40.664	-0.128	18	27.089	0.416	20	13.805	0.696
γ	150000	23	18	41.834	0.577	19	28.032	1.048	21	14.536	1.239
	500000	22	17	40.425	-0.272	18	26.896	0.288	20	13.656	0.586
β	1.08	15	5	294.158	-10.368	6	261.347	-8.567	7	228.762	-6.851
	1.6	29	41	-44.836	-6.219	44	-51.891	-8.951	47	-58.571	-12.168
A	40	23	18	40.88	0.073	20	27.172	0.525	21	13.762	0.698
	200	22	16	41.364	0.192	17	27.776	0.797	19	14.474	1.142
S	150	21	16	40.516	-0.265	17	27.029	0.339	19	13.826	0.689
	600	25	19	41.738	0.617	21	27.832	0.987	22	14.234	1.064
h	1	22	17	40.724	-0.0924	18	27.138	0.448	20	13.842	0.724
	32	24	18	42.212	0.807	19	28.338	1.255	21	14.768	1.417
H	0.5	22	17	40.915	0.022	18	27.292	0.551	20	13.96	0.812
	1.2	22	17	40.913	0.022	18	27.29	0.55	20	13.96	0.812
k_1	500	22	17	40.887	0.002	18	27.273	0.536	18	13.785	3.192
	2000	22	17	40.968	0.061	19	27.327	0.579	20	13.979	0.828
k_2	0.0001	22	17	40.915	0.022	18	27.292	0.551	20	13.96	0.812
	0.001	22	17	40.911	0.02	18	27.288	0.549	20	13.959	0.81
l	0.01	22	17	40.887	0.002	18	27.273	0.536	20	13.951	0.804
	0.1	23	18	41.128	0.177	19	27.431	0.664	21	14.031	0.877

We solve 101 problems and drive conclusions about the results. To evaluate the RFM policy, we set α to 0.74, but other parameters generated randomly from the intervals as below:

$$c \in [7,18], \gamma \in [150000,500000], \beta \in [1.08,1.6], A \in [40,200], S \in [150,600],$$
$$h \in [1,3], H \in [0.5,1.2], k_1 \in [500,2000], k_2 \in [0.0001,0.001], l \in [0.01,0.1].$$

Next, we compare the competition penalty for these problems. The penalty's histogram for RFM and Stackelberg policies can be seen in Figure 5. The figure shows that the highest and the lowest frequency of the competition penalty of Stackelberg policy are $\rho \in$ [22%, 22.5%] and $\rho <$ 21%, respectively. The highest frequency of competition penalty of RFM policy is $\rho \in$ [17%, 18%]; whereas the lowest one is $\rho <$ 15% and $\rho \in$ [15%, 16%].

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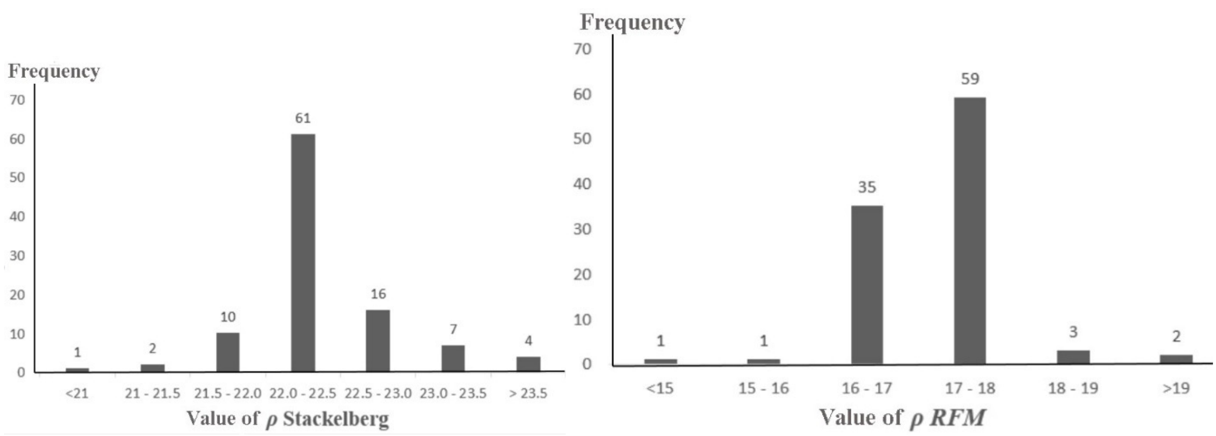
Table 3. Two approach solutions under variation of major parameters.

Solutions→		Integrated		Stackelberg			RFM (0.74)			RFM (0.76)			RFM (0.78)		
Paramaters ↓		Q^*	p^*	Q^*	p^*	w^*	Q^*	p^*	w^*	Q^*	p^*	w^*	Q^*	p^*	w^*
c	7	1495	36.438	216	221.8	43.9	268	158.032	41.088	253	172.617	41.428	239	190.097	41.821
	18	836	92.495	125	530.26	105.414	153	386.84	100.578	145	421.481	101.155	137	462.824	101.82
γ	150000	717	67.892	102	423.511	83.918	127	298.895	77.712	120	326.819	78.436	113	360.346	79.276
	500000	1324	66.611	201	375.275	74.657	244	275.643	71.667	232	300.107	72.025	219	329.268	72.439
β	1.08	851	182.116	80	3286.44	242.437	175	771.221	200.517	167	840.384	201.692	159	922.895	203.04
	1.6	804	36.047	145	112.222	41.531	107	164.268	42.709	100	180.576	43.338	92	200.395	44.087
A	40	970	66.957	104	412.235	82.062	127	298.895	77.712	120	326.819	78.436	113	360.346	79.276
	200	1161	67.340	245	378.628	74.908	302	270.78	70.402	287	294.537	70.689	271	322.811	71.018
S	150	811	66.643	158	364.969	72.489	193	267.382	69.519	183	90.649	69.755	173	318.309	70.028
	600	1343	67.707	139	451.781	89.779	173	319.699	83.121	163	350.83	84.199	153	388.427	85.454
h	1	1121	66.886	168	385.118	76.647	205	280.477	72.924	194	305.65	73.355	183	335.701	73.854
	3	639	68.231	90	437.296	86.565	112	305.349	79.390	106	334.259	80.222	100	369.032	81.187
H	0.5	1022	67.034	152	391.34	77.74	186	283.473	73.703	176	309.093	74.182	166	339.71	74.736
	1.2	1021	67.108	152	391.536	77.779	186	283.618	73.740	176	309.251	74.220	166	1339.883	74.774
k_1	500	1009	67.037	153	389.642	77.402	186	282.46	73.439	177	307.925	73.902	167	338.345	67.743
	2000	1046	67.108	151	395.189	78.507	185	285.826	74.314	175	311.789	74.829	165	342.836	75.424
k_2	0.0001	1022	67.037	152	391.34	77.74	186	283.473	73.703	176	309.093	74.182	166	339.71	74.736
	0.001	1019	67.263	151	392.598	77.991	186	284.407	73.945	176	310.109	74.426	166	340.823	74.981
l	0.01	1009	67.059	152	389.781	77.429	186	282.564	73.466	177	308.037	73.929	166	338.468	74.462
	0.1	1115	67.413	148	407.484	80.956	182	293.381	76.279	172	320.431	76.903	162	352.847	77.626



(a) (b)

Figure 5. Histogram of (a) Stackelberg policy's penalty and (b) RFM policy's penalty.

Figure 6 illustrates the variations of total profit, retailer's profit and manufacturer's profit respect to the retailer's fixed ordering cost. It can be seen that total profit of the RFM policy is higher than that of Stackelberg policy. Moreover, it is shown that greater value of α leads to lower profit for the manufacturer, but greater profit for the retailer. It is obvious that with $\alpha = 0.74$ is preferred by the retailer. However, manufacturer may choose $\alpha = 0.6$ to maximize his profit.

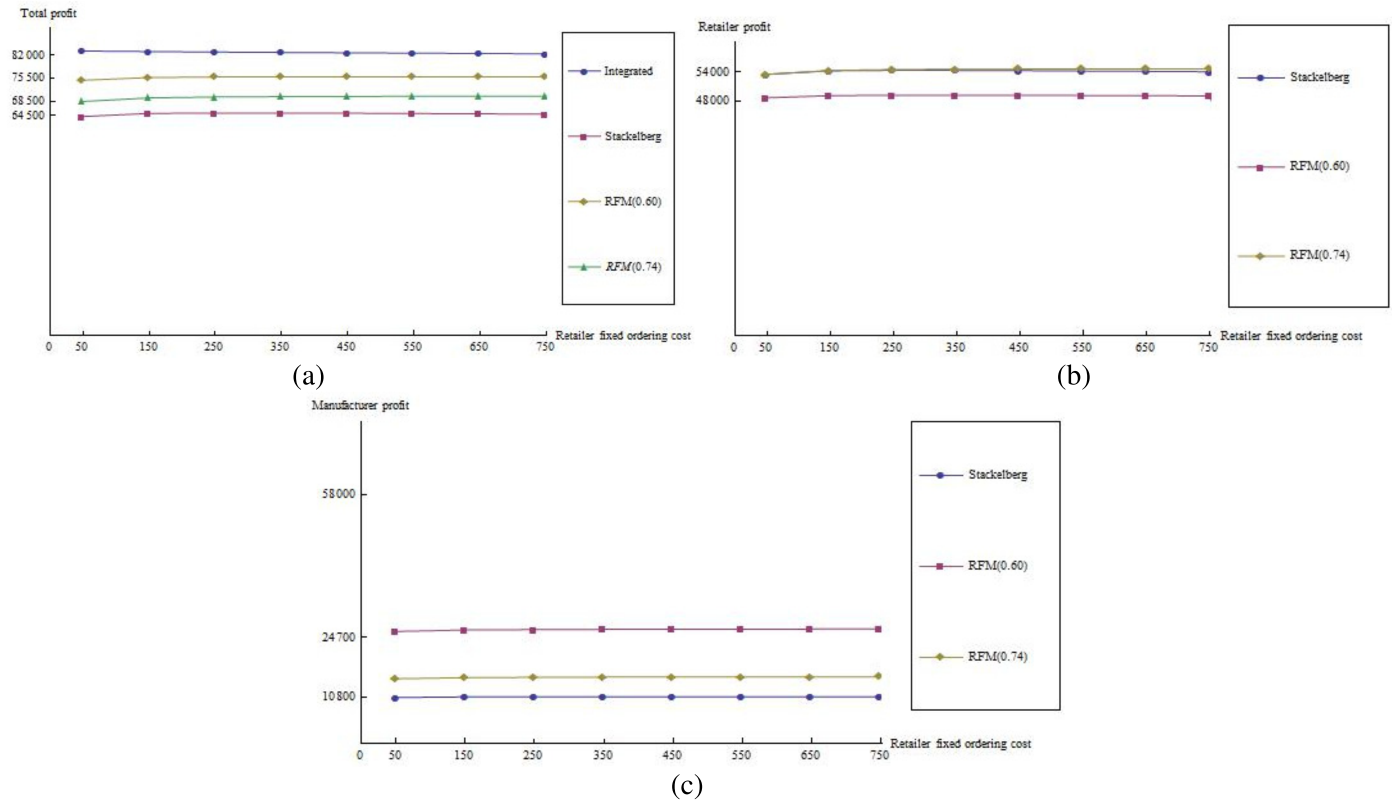


Figure 6. (a) Total profit, (b) retailer profit, and (c) manufacturer profit respect to retailer fixed ordering cost.

The variations of retail price and order quantity respect to the procurement cost are illustrated in Figure 7. We examine four different values of fixed mark-up, α. It can be seen that the greater the procurement cost, the greater the retail price, but the lower the order quantity. Moreover, the retail price of Stackelberg policy is greater than that of integrated policy. However, the order quantity of integrated policy is greater than those of Stackelberg and RFM policies.

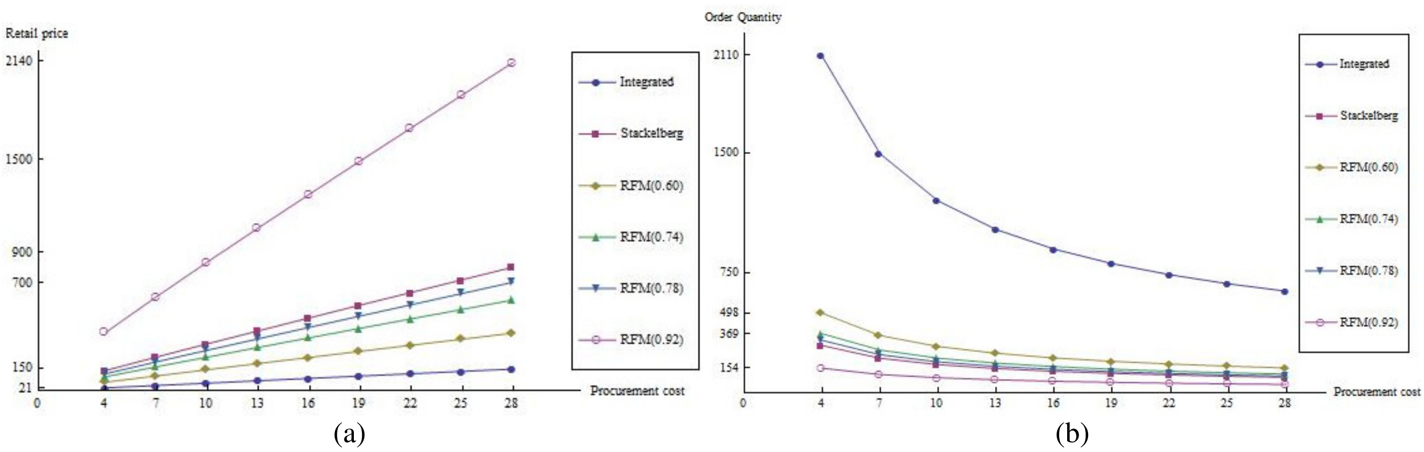


Figure 7. (a) Retail price and (b) order quantity respect to the procurement cost.

7. Conclusions

In this paper, we consider a production-inventory supply chain system with single-manufacturer and single-retailer. The decentralized policies (*i.e.* Stackelberg and RFM) are examined with the goal of coordinating the channel. There are many types of contract that guarantee the supply chain. However, the administrative costs of the contract are usually neglected in real situation. The additional gain from integration may not cover the extra administrative costs and may not be addressed to supply chain. Therefore, RFM policy is used it has minor administrative costs comparing to the other policies. With properly designed RFM policy, Pareto improvement is obtained over the Stackelberg policy. Although the RFM policy is not capable of coordinating the channel, it leads to considerable improvements over the channel. Possible extensions for future research could be by considering other general demand function with more efficient inventory models. Furthermore, it is also interesting to consider the administrative costs of the integration contracts in the objective function of the members.

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