International Journal of
Operations Research

International Journal of Operations Research Vol. 8, No. 3, 24–33 (2011)

Optimal Supply Chain Strategy for Varying Production Cost

Ping-Hui Hsu*

Department of Business Administration, De Lin Institute of Technology,

No. 1, Lane 380, Ching-Yun Rd, Tu-Cheng

New Taipei, Taiwan, 236, R.O.C.

Received January 2011; Revised June 2011; Accepted July 2011

Abstract —Changes in production cost always lead to changes in wholesale and retail price. How to adjust the wholesale price, retail price and order quantity in order to derive an optimal strategy for the supplier and the retailer is one of the most perplexing problems. The purpose of this study is to develop a strategy to maximize the expected profit by simultaneously determining the adjustment ratio of wholesale/retail price and the order quantity under customer's uncertain and price-sensitive demand. A coordinated policy is proposed. Numerical examples and sensitivity analysis are provided to illustrate the theory.

Keywords — Production cost change, coordination, newsboy problem, compensation mechanism.

1. INTRODUCTION

The unpredictable price fluctuation of raw materials significantly influences the production cost (Ren, et al. 2009). One typical instance of production cost increase is the impact of weather that reduces the harvest of grains, vegetables, or fruits. When the production cost increases, the supplier has to increase the wholesale price in order to meet the supplier's profit. Adjusting retail price is especially important when customers pay more attention to both quality and price of the products. To adjust the selling price is an important task for the manager. The classical economic production lot size model assumes a predetermined and constant production rate. The unit production cost depends on the production rate. Khouja (1995) extended the economic production lot size model to consider the variable production rate.

Comparative pricing practices are frequently used where actual product prices are accompanied by high external reference prices. All types of stores, regular-price department stores as well as discount stores, use comparative price claims to frame price as an attractive deal (Thaler, 1985; Kogan and Spiegel 2006). Kopalle and Lindsey-Mullikin (2003) used a quadratic model to consider the impact of external reference price on consumer's price expectation. However, the impact of production cost changes has received little attention from previous researches.

Abuo-El-Ata et al. (2003) treated a probabilistic multi-item inventory model with varying order cost and zero lead time. Wu and Chang (2004) assessed an optimal production-planning program in response to varying environmental costs in an uncertain environment. Furthermore, the supplier-retailer coordination which improved the performance of inventory control had received a lot of attention in recent years (Goyal and Gupta, 1989; Fites, 1996; Khouja et.al., 2010; Weng, 1997; Zimmer, 2002; Sucky, 2005; Krichen et al., 2011). Since the last decade, several researchers have studied the integrated inventory models when the suppliers and the retailers coordinate their production and ordering policies in order to achieve a higher joint profit. Information exchange is an important issue for coordination (Schouten et al., 1994). Fiala (2005) addressed the cooperation in supply chain based on formal agreements.

This study considers a newsboy problem in three echelon supply chain. A supply chain considering one supplier and one retailer is assumed. The retailer purchases the product from the supplier and sells to its customers. Due to the change in production cost, the supplier adjusts its retailer's wholesale purchase price. The retailer's selling price is based on the production cost and customer's demand. The well known newsboy problem had received a lot of research (Khouja, 1999; Hsu et al., 2007). Li and Liu (2008) focused on the second order policy, that is: In order to meet a random demand, the

* Corresponding author's email: pinghuihsu@gmail.com

retailer place a second order at the end of the period if a stock-out occurs. The manufacturer's reserve capacity for the retailer's second order is limited to M units. To maximize each individual's expected profit, the retailer decides his optimal order quantity and the manufacturer decides his optimal reserve capacity. However, little researches had considered production cost change. This study focused on the response of wholesale and retail price as the production cost changes. That is: changes in production cost leads to changes in wholesale and retail price. The purpose is to develop a strategy to maximize the expected profit by simultaneously determining the adjustment ratio of wholesale/retail price and the order quantity under customer's uncertain and price-sensitive demand. We suggest a strategy to determine the retailer's selling price, order quantity, and supplier's whole purchase price considering the price change from the supplier. Moreover, if the supplier and retailer coordinate, then we obtain the optimal order quantity.

We suggest three cases and compare the policy with coordination and without coordination. The three cases are: (1) the adjustment ratio for both the retailer's wholesale purchase price (wholesale price) and the retailer's selling price (retail price) are fixed; (2) the adjustment ratio for the wholesale price is fixed whereas for the retailer price is variable; and (3) the adjustment ratio for both the wholesale price and the retailer price are variable. Practically, the retailer price always depends on the wholesale price. It is not needed to discuss the last case that is the adjustment ratio for the wholesale price is variable and retailer price is fixed.

2. ASSUMPTIONS AND NOTATION

In this study, a supply chains with a retailer and a supplier is assumed. The retailer obtains the products from the supplier for sale to the customers. The retailer has to consider the uncertainty of customers' demand and the production cost change. Placing an optimal order before the selling period of the product is important to the retailer.

The following notation is used throughout this paper.

The decision variables are

k_b adjustment ratio for the retail price without coordination, $k_b > 0$

k_{bJ} adjustment ratio for the retail price with coordination, $k_{bJ} > 0$

k_s adjustment ratio for the wholesale price; $0 \le k_s \le 1$, $k_s > 0$

The parameters related to the supplier are

c_o supplier's original wholesale price per unit

t supplier's original production cost per unit; $t < c_o$

δ supplier's varied production cost per unit

E_s supplier's expected profit

E_{xs} supplier's extra profit

S_{Js} supplier's actually expected profit after distribution contract

The parameters related to the retailer are

p retail original price per unit; $p > c_o$

s retailer's salvage value per unit

r retailer's shortage cost per unit; represents costs of lost goodwill

x random demand faced by the retailer

$f(x)$ probability density function of x

Q_b retailer's order quantity without coordination

Q_J retailer's order quantity with coordination

E_b retailer's expected profit

E_{xb} retailer's extra profit

S_{Jb} retailer's actually expected profit after distribution contract

The other related parameters are as follows:

θ negotiation factor ($\theta \ge 0$)

E expected system profit ($E = E_b + E_s$)

3. MODELING AND ANALYSIS

In this section, we formulate an expected profit model for the retailer and the supplier using newsboy's model (Hadley and Whitin, 1963). When the production cost changes from t to $t+\delta$, the supplier adjusts its wholesale price from c_o to $c_o+k_s\delta$. The retailer taking into consideration of cost and customer's demand, responds to this change, and adjusts the retail price from p to $p+k_b\delta$. With the customer's random demand, x, the retailer orders quantity Q_b from the supplier, the retailer's expected profit is

$$E_b = \int_0^{Q_b} \{[(p+k_b\delta)-(c_o+k_s\delta)]x-(c_o+k_s\delta-s)(Q_b-x)\} f(x)dx$$
$$+\int_{Q_b}^{\infty} \{[(p+k_b\delta)-(c_o+k_s\delta)]Q_b-r(x-Q_b)\} f(x)dx, \tag{1}$$

where $f(x)$ is the probability density function of x. The supplier's expected profit is

$$E_s = Q_b\left[c_o+k_s\delta-(t+\delta)\right]. \tag{2}$$

The expected system profit is

$$E = E_b + E_s\ . \tag{3}$$

Theorem 1. $E=E_b+E_s$ is independent of k_s.
Proof: Please refer to Appendix A.

When the retailer derives the optimal order quantity independently, the optimal order quantity is derived from Theorem 2.

Theorem 2. The retailer's optimal order quantity without coordination, Q_b*, satisfies the following expression:

$$F\left(Q_b^*\right)=\frac{\left(p+k_b\delta\right)-\left(c_o+k_s\delta\right)+r}{p+k_b\delta-s+r}. \tag{4}$$

Proof: Please refer to Appendix B.

When $\delta=0$, Theorem 2 results in a well-known "newsboy" [Hadley and Whitin 1963]. From Theorem 2, since Q_b^* is a function of k_b and k_s, the retailer's optimal expected profit, $E_b^*(Q_b^*(k_b,k_s))$, is also a function of k_b and k_s. The supplier's expected profit is $E_s(Q_b^*(k_b,k_s))$, and the expected system profit is

$$E(Q_b^*(k_b,k_s))=E_b^*\ (Q_b^*(k_b,k_s))+E_s(Q_b^*(k_b,k_s)). \tag{5}$$

If the retailer and the supplier coordinate by sharing their production and demand information, an order quantity of Q_J results in the expected system profit, $E(Q_J)= E_b(Q_J)+ E_s(Q_J)$.

Theorem 3. The retailer's optimal order quantity with coordination, Q_J*, satisfies the following expression:

$$F\left(Q_J^*\right)=\frac{\left(p+k_b\delta\right)-\left(c_o+k_s\delta\right)+r+c_o+k_s\delta-\left(t+\delta\right)}{p+k_b\delta-s+r}. \tag{6}$$

Proof: Please refer to Appendix C.

From Theorem 3, since Q_J* is a function of k_b and k_s, the retailer's expected profit is $E_b(Q_J^*(k_b,k_s))$, the supplier's expected profit is $E_s(Q_J^*(k_b,k_s))$, the optimal expected system profit is

$$E^*(Q_J^*(k_b,k_s))=E_b(Q_J^*(k_b,k_s))+E_s(Q_J^*(k_b,k_s)). \tag{7}$$

It is obviously that $E(Q_J*) \geq E(Q_b*)$ (please refer to Appendix D). Some player may lose profit under the order quantity, Q_J*. However, a win-win strategy can be achieved through a compensation mechanism if they share their production and demand information during the coordination.

Compensation mechanism

Although there is an increase in the expected system profit with coordination, the gain is always unilateral. We assume the distribution contract of the optimal expected system profit with coordination as compensating the retailer's loss $[E_b(Q_b*)-E_b(Q_J*)]$, The remaining value $K=[E_s(Q_J*)-E_s(Q_b*)]-[E_b(Q_b*)-E_b(Q_J*)] =E(Q_J*)-E(Q_b*)$, follows the distribution ratio of $E_{xb}=\theta E_{xs}$, where θ is the negotiation factor; E_{xb} , is the retailer's extra profit; E_{xs}, is the supplier's extra profit

then $E_{xb}=\dfrac{\theta K}{\theta+1}$, $E_{xs}=\dfrac{K}{\theta+1}$, the retailer's actual expected profit after distribution contract is $S_{Jb}=E_b(Q_b^*)+\dfrac{\theta K}{\theta+1}$, the supplier's actual expected profit after distribution contract is $S_{Js}=E_S(Q_b^*)+\dfrac{K}{\theta+1}$.

The following three cases consider the system with and without coordination.

3.1. Case 1: when k_s, k_b are fixed

That is, the adjustment ratio for the wholesale price, k_s, is predetermined by the supplier. The adjustment ratio for the retail price without coordination, k_b, is predetermined by the retailer. In this case, given $k_b=k_{b0}$, $k_s=k_{s0}$, the retailer's optimal order quantity without coordination, $Q_b*(k_{b0},k_{s0})$ is derived as follows:

$$F\left(Q_b^*(k_{b0},k_{s0})\right)=\frac{\left(p+k_{b0}\delta\right)-\left(c_o+k_{s0}\delta\right)+r}{p+k_{b0}\delta-s+r}.$$

The retailer's optimal order quantity with coordination, $Q_J*(k_{b0}, k_{s0})$, is derived as follows:

$$F\left(Q_J^*(k_{b0},k_{s0})\right)=\frac{\left(p+k_{b0}\delta\right)-\left(c_o+k_{s0}\delta\right)+r+c_o+k_{s0}\delta-\left(t+\delta\right)}{p+k_{b0}\delta-s+r}.$$

3.2. Case 2: when k_s is fixed and k_b is variable

That is, the adjustment ratio for the wholesale price, $k_s=k_{s0}$, is predetermined by the supplier. The adjustment ratio for the retail price without coordination, k_b, is treated as variable by the retailer.

(i) Without coordination

By solving the equation $\dfrac{d}{dk_b}E_b(Q_b*(k_b,k_{s0}))=0$, the optimal k_b* is derived. The retailer's optimal order quantity without coordination, $Q_b*(k_b*,k_{s0})$ is derived from Eq.(4), the expected system profit is

$$E(Q_b*(k_b*,k_{s0}))=E_b*(Q_b*(k_b*,k_{s0}))+E_s(Q_b*(k_b*,k_{s0})). \tag{8}$$

(ii) With coordination

If the retailer and the supplier determine jointly the order quantity Q_J for the optimal expected system profit, the optimal $k_{bJ}*$ can be derived by setting $\dfrac{d}{dk_{bJ}}E(Q_J*(k_{bJ},k_{s0}))=0$, then the retailer's optimal order quantity with coordination, $Q_J*(k_{bJ}*,k_{s0})$ is derived from Eq.(6), and the optimal expected system profit is

$$E*(Q_J*(k_{bJ}*,k_{s0}))=E_b(Q_J*(k_{bJ}*,k_{s0}))+E_s(Q_J*(k_{bJ}*,k_{s0})). \tag{9}$$

It is clear from Theorem 3 that regardless of the k_s the expected system profit will be the same, so if both sides can agree on an optimal order quantity with coordination, Q_J*, and adjustment ratio, $k_{bJ}*$, then both sides can reach more profit through compensation mechanism.

3.3. Case 3: when both k_s and k_b are variable

That is, the adjustment ratio for the wholesale price, k_s, is treated as variable by the supplier. The adjustment ratio for the retail price without coordination, k_b, is treated as variable by the retailer.

(i) Without coordination

When the retailer determines Q_b, k_b, and k_s independently, the optimal (k_b*, k_s*) can be derived by setting $\frac{\partial}{\partial k_b} E_b(Q_b{}^*(k_b, k_s))=0$ and $\frac{\partial}{\partial k_s} E_b(Q_b{}^*(k_b, k_s))=0$. Hence the retailer's optimal expected profit is $E_b{}^*(Q_b{}^*(k_b{}^*, k_s{}^*))$, and the expected system profit is

$$E(Q_b{}^*(k_b{}^*, k_s{}^*))=E_b{}^*(Q_b{}^*(k_b{}^*, k_s{}^*))+E_s(Q_b{}^*(k_b{}^*, k_s{}^*)). \tag{10}$$

(ii) With coordination

Since $E=E_b+E_s$ is independent of k_s by Theorem 3, the optimal expected system profit is $E^*(Q_J{}^*(k_{bJ}{}^*, k_s))$, regardless of k_s.

4. NUMERICAL EXAMPLES

The random demand faced by the retailer, x, is uniformly distributed over the range 0 and $B/(1+ak_b)^2$, where a, $B>0$ are constant (a represents the magnitude of the selling price fluctuation), the probability density function of x is

$$f(x)=\frac{(1+ak_b)^2}{B}, \quad x\in[0, \frac{B}{(1+ak_b)^2}]. \tag{11}$$

The cumulative distribution function of x is

$$F(x)=\frac{(1+ak_b)^2 x}{B}, \quad x\in[0, \frac{B}{(1+ak_b)^2}]. \tag{12}$$

A simple economic interpretation of the random demand is as follows: When the adjustment ratio for the retail price, k_b, increases, the customer's demand decreases.

From (4), one has

$$Q_b{}^*(k_b, k_s)= \frac{B}{(1+ak_b)^2} \frac{(p+k_b\delta)-(c_o+k_s\delta)+r}{p+k_b\delta-s+r}. \tag{13}$$

From (6), one has

$$Q_J{}^*(k_{bJ}, k_s)= \frac{B}{(1+ak_{bJ})^2} \frac{(p+k_{bJ}\delta)-(c_o+k_s\delta)+r+c_o+k_s\delta-(t+\delta)}{p+k_{bJ}\delta-s+r}. \tag{14}$$

Example 1. Case 1:

$t=400$, $\delta=50$, $c_o=550$, $p=700$, $s=150$, $r=25$, $B=1000$, $a=1$, $k_s=0.7$, $k_b=0.9$, and $\theta=2$, then

Q_b*= 82,656, $E_b{}^*(Q_b{}^*)$= \$4183, $E_s(Q_b{}^*)$=\$11159, $E(Q_b{}^*)$=\$15342,

Q_J*=142.972, $E_b(Q_J{}^*)$=\$111.7, $E_s(Q_J{}^*)$=\$19301, $E^*(Q_J{}^*)$=\$19413.

% profit increase is $[(E^*(Q_J{}^*)-E(Q_b{}^*))/E(Q_b{}^*)]\times 100\%$=26.5%.

E_{xb}=\$2714, E_{xs}=\$1357, S_{Jb}=\$6897, and S_{Js}=\$12516.

Sensitivity Analysis

Sensitivity analysis with parameters a, k_b and k_s changes are carried out in this section. Table 1 and Figure 1 show the changes of Q_b*, $E(Q_b{}^*)$, Q_J* and $E^*(Q_J{}^*)$ for parameter a equals to 0.5, 1, 1.5; for parameter k_b equals to 0.2, 0.5, 0.8; for parameter k_s= 0.3 and other fixed parameters. Table 2 and Figure 2 show the change of Q_b*, $E(Q_b{}^*)$, Q_J* and $E^*(Q_J{}^*)$ for parameter k_s= 0.5. Table 3 and Figure 3 show the changes of Q_b*, $E(Q_b{}^*)$, Q_J* and $E^*(Q_J{}^*)$ for parameter k_s= 0.7. Table 4 shows the changes of S_{Jb} and S_{Js} for negotiation factor θ.

(1) When a increases, which leads to % profit increase unchanged, Q_b*, Q_J*, $E_b(Q_b^*)$, $E_s(Q_b^*)$, $E_b(Q_J^*)$ and $E_s(Q_J^*)$ decrease. Which means the more magnitude of the selling price fluctuation is, the less profit for both players will be.
(2) When k_b increases, which leads to a decrease of % profit increase, Q_b*, Q_J*, $E(Q_b^*)$ and $E^*(Q_J^*)$, that means an increase in retail price will decrease profit for both players.
(3) When k_s increases, which leads to an increase of % profit increase and $E_s(Q_b^*)$, however, Q_b*, $E_b(Q_b^*)$ and $E(Q_b^*)$ decrease, both Q_J* and $E^*(Q_J^*)$ are still unchanged.

Table 1 Sensitivity analysis for parameters a, k_b with k_s= 0.3

t = 400, δ =50, c_0 =550, p =700, s =150, r =25, B =1000, k_s= 0.3

a	k_b	Q_b*	$E_b^*(Q_b^*)$	$E_s(Q_b^*)$	without coordination $E(Q_b^*)$	Q_J*	$E_b(Q_J^*)$	$E_s(Q_J^*)$	with coordination $E^*(Q_J^*)$	%profit increase
0.5	0.2	240	10083	27619	37702	403	742	46302	47044	24.8%
1	0.2	202	8473	23207	31680	338	623	38907	39530	24.8%
1.5	0.2	172	7219	19775	26994	288	531	33151	33682	24.8%
0.5	0.5	197	10253	22693	32947	320	3200	36800	40000	21.4%
1	0.5	137	7120	15760	22880	222	2222	25556	27778	21.4%
1.5	0.5	101	5231	11578	16810	163	1633	18775	20408	21.4%
0.5	0.8	166	10214	19081	29295	261	4729	30052	34781	18.7%
1	0.8	100	6179	11543	17722	158	2860	18180	21040	18.7%
1.5	0.8	67	4136	7727	11863	106	1915	12170	14085	18.7%

Note: % profit increase is $[(E^*(Q_J^*)–E(Q_b^*))/\ E(Q_b^*)]\times 100\%$

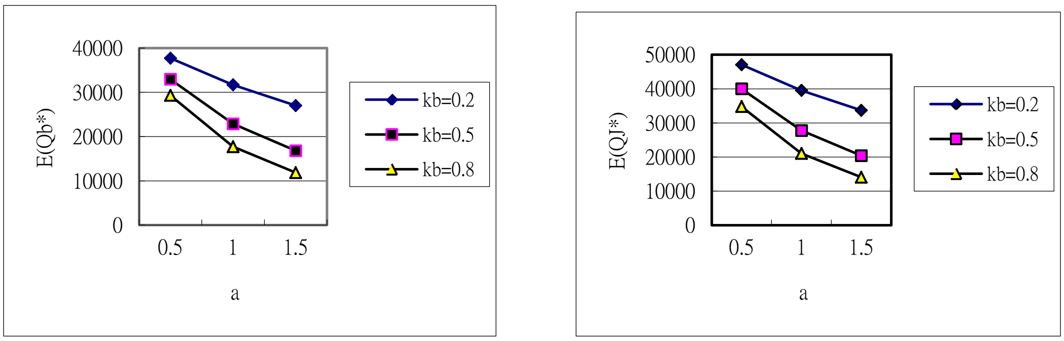

Figure 1 The effect of retailer's adjustment ratio k_b on the expected profit: with v.s. without coordination when k_s= 0.3.

Table 2 Sensitivity analysis for parameters a, k_b with k_s= 0.5

t = 400, δ =50, c_0 =550, p =700, s =150, r =25, B =1000, k_s= 0.5

a	k_b	Q_b*	$E_b^*(Q_b^*)$	$E_s(Q_b^*)$	without coordination $E(Q_b^*)$	Q_J*	$E_b(Q_J^*)$	$E_s(Q_J^*)$	with coordination $E^*(Q_J^*)$	%profit increase
0.5	0.2	226	7752	28255	36007	403	-32845	50329	47044	30.7%
1	0.2	190	6514	23742	30256	338	-2760	42290	39530	30.7%
1.5	0.2	162	5551	20230	25780	288	-2352	36034	33682	30.7%
0.5	0.5	187	8334	23333	31667	320	0	40000	40000	26.3%
1	0.5	130	5787	16204	21991	222	0	27778	27778	26.3%
1.5	0.5	95	4252	11905	16157	163	0	20408	20408	26.3%
0.5	0.8	158	8597	19703	28300	261	2116	32665	34781	22.9%
1	0.8	95	5200	11919	17119	158	1280	19760	21040	22.9%
1.5	0.8	64	3481	7979	11460	106	857	13228	14085	22.9%

Shu: *Optimal Supply Chain Strategy for Varying Production Cost*
IJOR Vol. 8, No. 3, 24–33 (2011)

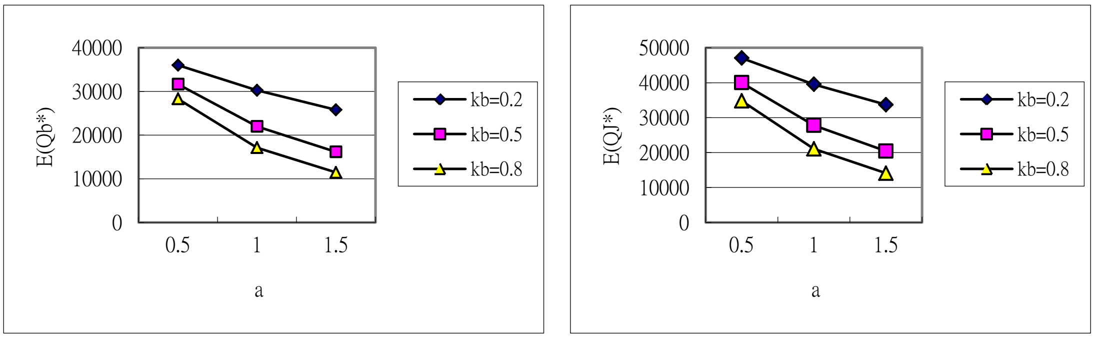

Figure 2 The effect of retailer's adjustment ratio k_b on the expected profit: with v.s. without coordination when k_s= 0.5.

Table 3 Sensitivity analysis for parameters *a*, k_b with k_s= 0.7

t = 400, δ =50, c_o =550, p =700, s =150, r =25, B =1000, k_s= 0.7

a	k_b	Q_b*	E_b*(Q_b*)	E_s(Q_b*)	without coordination E(Q_b*)	Q_J*	E_b(Q_J*)	E_s(Q_J*)	with coordination E*(Q_J*)	%profit increase
0.5	0.2	212	5563	28607	34170	403	-7311	54355	47044	37.7%
1	0.2	178	4674	24039	28713	338	-6143	45673	39530	37.7%
1.5	0.2	152	3983	20482	24465	288	-5234	38916	33682	37.7%
0.5	0.5	176	6520	23760	30280	320	-3200	43200	40000	32.1%
1	0.5	122	4528	16500	21028	222	-2222	30000	27778	32.1%
1.5	0.5	90	3327	12122	15449	163	-1632	22040	20408	32.1%
0.5	0.8	149	7062	20159	27221	261	-498	35279	34781	27.8%
1	0.8	90	4272	12195	16467	158	-301	21341	21040	27.8%
1.5	0.8	60	2860	8164	11024	106	-201	14286	14085	27.8%

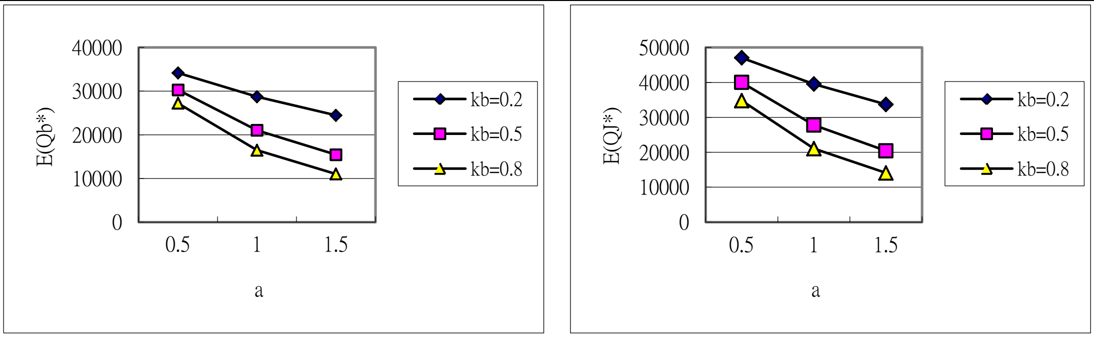

Figure 3 The effect of retailer's adjustment ratio k_b on the expected profit: with v.s. without coordination when k_s= 0.7.

Table 4 Sensitivity analysis for negotiation factor θ

t = 400, δ =50, c_o =550, p =700, s =150, r =25, B =1000, θ=2, k_s= 0.7, a =1, k_b=0.9

θ	$E_b(Q_b^*)$	E_{xb}	S_{Jb}	$E_s(Q_b^*)$	E_{xs}	S_{Js}
0.5	4183	1357	5540	11159	2714	13873
1	4183	2036	6219	11159	2036	13194
2	4183	2714	6897	11159	1357	12516

Table 5 Sensitivity analysis for parameters *a* and k_s

t = 400, δ =50, c_o =550, p =700, s =150, r =25, B =1000

a	k_{s0}	k_b*	Q_b*	$E_b^*(k_b^*,k_{s0})$	$E_s(k_b^*,k_{s0})$	$E(k_b^*,k_{s0})$	k_{bJ}^*	Q_J*	$E_b(k_{bJ}^*,k_{s0})$	$E_s(k_{bJ}^*,k_{s0})$	$E^*(k_{bJ}^*,k_{s0})$	%profit increase
0.5	0.3	0.569	189.3	10258	21767	32026	0	478.3	-1739	55000	53261	66.3%
1	0.3	0	278.2	9760	31995	41755	0	478.3	-1739	55000	53261	27.6%
1.5	0.3	0	278.3	9761	32000	41761	0	478.3	-1739	55000	53261	27.5%
0.5	0.5	1.165	131.3	8682	16415	25097	0	478.3	-6522	59783	53261	112.2%
1	0.5	0	260.8	7065	32603	39668	0	478.3	-6522	59783	53261	34.3%
1.5	0.5	0	260.9	7065	32608	39675	0	478.3	-6522	59783	53261	34.2%
0.5	0.7	1.776	96.7	7555	13056	20611	0	478.3	-11304	64565	53261	158.4%
1	0.7	0.194	180.0	4674	24300	28974	0	478.3	-11304	64565	53261	83.8%
1.5	0.7	0	243.4	4543	32861	37404	0	478.3	-11304	64565	53261	42.4%

Example 2. Case 2:

t = 400, δ =50, c_o =550, p =700, s =150, r =25, B =1000, a =1 and k_{s0}= 0.7, then

k_b*=0.194, (p+k_b*δ =700+0.194*50=709.7), Q_b*=179.567, E_b*(Q_b*(k_b*,k_{s0}))= \$4674.23, E_s(Q_b*(k_b*,k_{s0}))= \$24242, E(Q_b*(k_b*,k_{s0}))= \$28916.
k_{bJ}*=0, Q_J*= 478.17, E_b(Q_J*(k_{bJ}*,k_{s0}))= -\$11292, E_s(Q_J*(k_{bJ}*,k_{s0}))= \$64553, E*(Q_J*(k_{bJ}*,k_{s0}))= \$53261.
% profit increase is [(E*(Q_J*(k_{bJ}*,k_{s0}))–E(Q_b*(k_b*,k_{s0})))/E(Q_b*(k_b*,k_{s0}))]×100%=84.2 %. From the analysis, if the supplier's production cost per unit is t+ δ =400+50=450, and the supplier's wholesale price per unit is c_o + k_{s0} δ =550+0.7*50=585, then the retail price per unit is p+k_b*δ =700+0.194*50=709.7.

Sensitivity Analysis

Sensitivity analysis with parameters a, k_s changes and k_b treated as variable are carried out in this section. Table 5 shows the changes of Q_b*, E(Q_b*), Q_J* and E(Q_J*), for parameter a equals to 0.5, 1, 1.5, and for parameter k_s equals to 0.3, 0.5, 0.7.

(1) When a increases, Q_b* increases, but k_b* decreases. It means when the magnitude of the selling price fluctuation gets higher, the adjustment ratio for the retailer's selling price should be reduced in order to boost the order quantity.
(2) Q_J* is the same since E(Q_J*) is independent of k_s. Also, because k_{bJ}* = 0, so Q_J* will not change regardless of a.
(3) When k_s increases, which leads to k_b* increases, but Q_b* decreases, at the same time E_b(Q_b*, k_b*), E_s(Q_b*, k_b*) and E(Q_b*, k_b*) decrease.

Example 3. Case 3:
t = 400, δ =50, c_o =550, p =700, s =150, r =25, B =1000 and a=0.5, then

k_s*=0, k_b*=0, Q_b*=304.348, E_b*(Q_b*(k_b*, k_s*))=\$14130, E_s(Q_b*(k_b*, k_s*))=\$30435, and E(Q_b*(k_b*, k_s*))=\$44565 is derived.
Since E is independent of k_s, it coincides with any k_s, and k_{bJ}*=0, Q_J*=478.3, E*(Q_J*(k_{bJ}*,k_s))= \$53261, the % profit increase is 19.5%.

5. CONCLUSION

Price fluctuation is a common phenomenon in the market. Both upstream and downstream supply chain need to respond to the production price change appropriately. How to establish a responding policy has become an important topic to the industry lately. This study considers uncertain customer's demand and price-sensitive model. We conclude that:

(1) When k_s is fixed and k_b is variable, if the supplier's production cost per unit, and the supplier's wholesale price per unit increase, then the optimal retail price per unit increase.
(2) When both k_s and k_b are variable, if the supplier's production cost per unit increase, then the optimal supplier's wholesale price per unit and the optimal retail price per unit still maintain. Therefore, compensation mechanism for the plays is needed.
(3) The optimal expected system profit will be better after coordination if both players share their production and demand information.
(4) The expected system profit is not affected by the adjustment ratio for the wholesale price. The increase in the retailer's wholesale purchase price will benefit the supplier but hurts the buyer. When the supplier increases the fixed adjustment ratio of the wholesale price, the retailer may reduce his profit. Therefore, the coordination must consider compensation mechanism.

ACKNOWLEDGEMENTS

This research was supported by De Lin Institute of Technology. The author thanks anonymous reviewers for their valuable comments to improve the paper.

REFERENCES

1. Abuo-El-Ata, M.O. Fergany, H.A. El-Wakeel, M.F. (2003). Probabilistic multi-item inventory model with varying order cost under two restrictions: A geometric programming approach. International Journal of Production Economics, 83(3): 223-231.
2. Fiala, P. (2005). Information sharing in supply chains. Omega, 33(5): 419-423.
3. Fites, D. (1996). Make your dealers your partners. Harvard Business Review, 74(6): 84–95.
4. Goyal, S. Gupta, Y. (1989). Integrated inventory models: The buyer–vendor coordination. European Journal of Operational Research, 41(3): 261–269.
5. Hadley, G. and Whitin, T. (1963). Analysis of Inventory Systems. Prentice-Hall, Englewood Cliffs, NJ.
6. Hsu, P.H. Teng, H.M, Jou, Y.T, Wee, H.M. (2007). Coordinated ordering decisions for products with short life cycle and variable selling price. Computers & Industrial Engineering, 54 (3): 602-612.
7. Khouja, M. (1995). The economic production lot size model under volume flexibility. Computers & Operations Research, 22(5): 515-523.
8. Khouja, M. (1999). The single-period (news-vendor) problem: Literature review and suggestions for future research. Omega, 27: 537-553.
9. Khouja, M. Rajagopalan, H.K. Sharer, E. (2010). Coordination and incentives in a supplier–retailer rental information goods supply chain. International Journal of Production Economics, 123(2): 279-289.
10. Kogan, K. Spiegel, U. (2006). Optimal policies for inventory usage, production and pricing of fashion goods over a selling season. Journal of the Operational Research Society, 57(12): 304-315.
11. Kopalle, P.K. Lindsey-Mullikin, J. (2003). The impact of external reference price on consumer price expectations. Journal of Retailing, 79(4): 225-236.
12. Krichen, S. Laabidi, A. Abdelaziz, F.B. (2011). Single supplier multiple cooperative retailers inventory model with quantity discount and permissible delay in payments. Computers & Industrial Engineering, 60(1): 164-172.
13. Li, J. Liu, L. (2008). Supply chain coordination with manufacturer's limited reserve capacity: An extended newsboy problem. International Journal of Production Economics, 112(2): 860-868.
14. Ren, T. Daniëls, B. Patel, M.K. Blok, K. (2009). Petrochemicals from oil, natural gas, coal and biomass: Production costs in 2030–2050 . Resources, Conservation and Recycling, 53(12): 653-663.
15. Sucky, E. (2005). Inventory management in supply chains: A bargaining problem. International Journal of Production Economics, 93-94: 253-262.
16. Thaler, R. (1985). Mental accounting and consumer choice. Marketing Science, 4: 199-214.
17. Van der D. Schouten, F. Van Eijs, M. Heuts, R. (1994). The value of supplier information to improve management of a retailer's inventory. Decision Sciences, 25(1): 1–14.
18. Weng, Z.K. (1997). Pricing and ordering strategies in manufacturing and distribution alliances. IIE Trans, 29(8): 681–692.
19. Wu, C.C. Chang, N.B. (2004). Corporate optimal production planning with varying environmental costs: A grey compromise programming approach. European Journal of Operational Research, 155(1): 68-95.
20. Zimmer, K. (2002). Supply chain coordination with uncertain just-in-time delivery. International Journal of Production Economics, 77(1): 1-15.

Appendix A: Proof of Theorem 1.

$$\begin{aligned} E = &\int_0^Q \left\{\left[\left(p+k_b\delta\right)-c_o\right]x-\left(c_o-s\right)\left(Q-x\right)\right\}f(x)dx \\ &+\int_0^Q \left[-k_s\delta x-k_s\delta\left(Q-x\right)\right]f(x)dx \\ &+\int_Q^\infty \left\{\left[\left(p+k_b\delta\right)-c_o\right]Q-r\left(x-Q\right)\right\}f(x)dx \\ &+\int_Q^\infty -k_s\delta Q f(x)dx \\ &+Q\ \left(c_o-t-\delta\right) \\ &+Qk_s\delta. \end{aligned} \tag{A1}$$

Combine the 2nd, 4th and 6th term of Eq.(A1) that vanish k_s. This completes the proof.

Appendix B: Proof of Theorem 2.

$$\frac{dE_b\left(Q_b\right)}{dQ_b}=\left(p+k_b\delta\right)-\left(c_o+k_s\delta\right)+r-\left(p+k_b\delta-s+r\right)F\left(Q_b\right), \tag{B1}$$

Shu: *Optimal Supply Chain Strategy for Varying Production Cost*
IJOR Vol. 8, No. 3, 24–33 (2011)

where $F(x) = \int_0^x f(y)dy$.

$$\frac{d^2}{dQ_b^2} E_b\left(Q_b\right) = -\left(p + k_b\delta - s + r\right) f\left(Q_b\right) < 0 \,. \tag{B2}$$

Which means $E_b(Q_b)$ is concave in Q_b, and Q_b* is derived by setting $\frac{d}{dQ_b} E_b\left(Q_b\right) = 0$, this completes the proof.

Appendix C: Proof of Theorem 3.

$$\frac{dE\left(Q_J\right)}{dQ_J} = \left(p + k_b\delta\right) - \left(c_o + k_s\delta\right) + r - \left(p + k_b\delta - s + r\right) F\left(Q_J\right) + \left[c_o + k_s\delta - \left(t + \delta\right)\right]. \tag{C1}$$

$$\frac{d^2E\left(Q_J\right)}{dQ_J^2} = -\left(p + k_b\delta - s + r\right) f(Q_b) < 0 \,. \tag{C2}$$

Then Q_J* is derived by setting $\frac{d}{dQ_J} E\left(Q_J\right) = 0$, this completes the proof.

Appendix D: Proof of $E(Q_J^*) \geq E(Q_b^*)$.

Since $E = E_b + E_s$, if Q_J* is an optimal solution of $E(Q)$, then $E(Q_J^*) \geq E(Q)$, for any Q. Therefore, $E(Q_J^*) \geq E(Q_b^*)$.