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Pricing strategy of dual-channel supply chain under joint promotion and retailer's capital constraint

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ABSTRACT

Under the condition of joint promotion and capital constraint on retailer, a dual-channel supply chain system with one risk neutral supplier and one risk neutral retailer selling the single product was analyzed in this paper, which set up the profit model of supplier dominated dual-channel system, studied to the optimal pricing strategies of decentralized and centralized supply chain, and obtained the sufficient conditions of optimal solution to the two kinds of supply chain system. It is observed from the optimal solution that the demand uncertainty of two distribution channels, deferred-payment rate, promotion cost and the retailer's sharing proportion of promotion cost etc, are all have certain influence relation on the pricing strategies of supply chain system. Numerical experiment has showed the effectiveness of the conclusions.

KEYWORDS

Joint promotion; Capital constraint; Pricing strategy; Deferred payment.

INTRODUCTION

With the rapid development of e-commerce, many brand manufacturers have begun to set up direct sales by introducing online channel. Such as Lenovo, Dell and Estee lauder so on, are all introduced online sales channel, they satisfied consumers requirements by the so-called "mouse + cement" dual-channel sales model[1]. But the introducing of online channel also gives rise to the channel conflict between supplier and retailer[2], and consequently lowers the efficiency of supply chain[3]. The dual-channel sales model also raised the new issue to supplier, under the condition that the coexistence of two sales channels, what way can the supplier adopt to stimulate the retailer develop market requirement, and realize the harmonious coexistence of traditional and internet direct sales channel? To stimulate the retailer developing the market, more and more suppliers proceeded joint promotion with retailer, such as shared a portion of promotion cost, sent their employees to participate in the sales promotion of retailers, and so on. At the same time, many enterprises faced with the problem of capital scarcity in reality, especially some small enterprises. Under the joint promotion and retailer's capital constraint, whether the price game between supplier and retailer has the equilibrium, which factors will affect their product pricing, the paper will attempt to resolve these problems.

Presently there have some research results on joint promotion, Zhang Juliang, Chen Jian[4] studied how to design the contract to maximize the profit of supply chain system when the production demand is random and rely on the retailer's efforts, but it is a single channel system. Yu Aimin, Liu Liwen[5] studied the competing and coordination strategies under the joint promotion. Aiming at the coexistence of traditional retail channel and the online sales channel within the supply chainn under e-commerce, Chen shuzhen etc[6] analysis the optimal promotion investment and pricing strategy of centralized and decentralized supply chain under the certain demand. Qu Daogang, Guoyajun[7] studied when the retailer's quantity demand is related to his promotion effort degree, how to realize the coordination of order quantity and sales effort by sharing contract.

There are also some researches on capital constraint; some researches[8-9] mainly focus on its influence on inventory control and pledge decision. There are also some research findings on supply chain financing, Lee etc[10] studied the coordination of price discount, buy-back, two-part tariff and revenue sharing four coordination mechanism to supply chain financing, subsequently, they studied supply chain with the trading credit from the supplier's view[11], and raised the coordinate contract under the condition of on sale and compensation mechanism. Gupta etc[12] analysis the optimal inventory decision by the relative algorithm of continuous time models, and it indicated that the supplier would automatically choose credit terms to coordinate the supply chain. Lai etc[13] indicated that when the retailer's capital is insufficient, the supplier would prefer to the sales model of combing retailer's advanced order and consignment sales; Based on the different roles of third party logistics in a capital constrained supply chain, Chen Xiangfeng etc[14] divided the structures of supply chain into three different types: convention model, delegation model and control model, and investigated the operational and financial decisions of firms under the supply chian with different type. Under the certain demands in traditional and online channels, Zhang Xiaojuan etc[15] studied a dual-channel supply chain model with the retailer's capital constrained, the deferred-payment model and the loan-payment model are analyzed respectively, obtained the optimal decisions of the supplier and retailer under the two modes, and proved that no matter how much the producing-budget owns, the supplier is always willing to provide the retailer a deferred-payment policy.

Although there are many research results on joint promotion or capital constraint dual-channel supply chain, the study on the dual-channel supply chain with the joint promotion and retailer's capital constrain is seldom, the paper studied the dual-channel supply chain combing with capital constraint and joint promotion, and built the profit model of dual-channel supply chain, studied the influence of joint promotion and retailer's capital constraint on supplier and retailer's pricing decision.

MODEL DESCRIPTION

We examine a dual-channel supply chain composed of one risk neutral supplier and one risk neutral retailer, the supplier may sell the products to the retailer, as well as to end customers directly. Customers can choose either the traditional or the online channel to buy the product. In order to express conveniently, all the relevant symbols are summarized in TABLE 1. Retailer and supplier's inventory levels to their random demand are x and y , respectively. The supplier's production mode to retailer is make-to-order; therefore the supplier and retailer are responsible for their inventory level, respectively.

The retailer's capital is insufficient, which financing solution way is accepting the deferred-payment mode provided by supplier, the retailer pays money B when order goods, the remaining payment and interest are paid after sale, the risk-free interest rate of business capital is 0.

Then the demand functions [16] of two channels are determined by:

$$Q_r = \rho A - \alpha_r p_r + \beta_r p_d + e + \varepsilon_r \tag{1}$$

$$Q_d = (1-\rho)A - \alpha_d p_d + \beta_d p_r + \varepsilon_d \tag{2}$$

It is assumed that $\alpha_r > \beta_r > 0$, $\alpha_d > \beta_d > 0$, which is very common in economics and operations management literatures, in order to simplified calculation, the paper assumes that $\alpha_r = \alpha_d = \alpha$, $\beta_r =$

$\beta_d = \beta$, and $\alpha > \beta$. e represents the retailer's promotion effort degree, retailer's sales promotion will enlarge the demand of traditional retail channel, and promotion cost $C(e) = 0.5\eta e^2$, where $\eta > 0$. To obtain the greater profits, the supplier would willing to share some promotion cost (such as training the retailer's promotion staff, sending the relate employees to participate in the sales promotion of retailers, and so on) to encourage the retailer's production promotion. Where $0 < t < 1$ depends on the results of the negotiations between supplier and retailer, so it is assumed that t is an exogenous variable.

So the expected demand functions in two channels are:

TABLE 1: Summarized symbols and their definitions

Symbols	Definitions	Symbols	Definitions
p_r	Price in the retail channel	p_d	Price in the online channel
t	Promotion cost proportion to retailer	Q_r	Total demand of retail channel
Q_d	total demand of online channel	A	The potential demand
ε_r	The random demand part of retail channel	μ_r	The mean of ε_r
$\sigma_r{}^2$	The variance of ε_r	(m_r, n_r)	The value interval of ε_r
$f(u)$	The probability density function of ε_r	$F(u)$	The distribution function of ε_r
ε_d	Random demand part of online channel	μ_d	The mean of ε_d
$\sigma_d{}^2$	The variance of ε_d	(m_d, n_d)	The value interval of ε_d
$g(u)$	The probability density function of ε_d	$G(u)$	The distribution function of ε_d
c	The supplier's unit production cost	s_m	Supplier's unit shortage cost
h_m	Supplier's unit inventory cost	s_r	Retailer's unit shortage cost
h_r	Retailer's unit inventory cost	B	Retailer's initial capital quantity
ρ	Customers' preference for retail channel	β_r , β_d	Cross-price elasticity
α_r	Self-price elasticity of retail channel	η	Promotion cost
α_d	Self-price elasticity of online channel	w	Wholesale price to retailer

$$E(Q_r)=\rho A - \alpha p_r + \beta p_d + \mu_r + e \quad \textbf{(3)}$$

$$E(Q_d)=(1-\rho)A - \alpha p_d + \beta p_r + \mu_d \quad \textbf{(4)}$$

When the capital is sufficient, the expected profit functions in two channels are as follows:

$$E(\Pi_r)=(p_r - w)E(Q_r) - h_r \int_{m_r}^{x} (x-u) f(u)du - s_r \int_{x}^{n_r} (u-x) f(u)du - tC(e) \quad \textbf{(5)}$$

$$E(\Pi_m)=(p_d - c)E(Q_d)+(w-c)E(Q_r) - h_m \int_{m_d}^{y} (y-u)g(u)du - s_m \int_{y}^{n_d} (u-y)g(u)du - (1-t)C(e) \quad \textbf{(6)}$$

The total expected profit of two channels can be written as follows:

$$E(\Pi)=E(\Pi_r)+E(\Pi_m) \quad \textbf{(7)}$$

MODEL ANALYSIS

Decentralized pricing strategy with joint promotion and capital constraint

This section focused on the decentralized dual-channel system, in which the retailer and supplier maximize their own profits respectively, the paper models the decision as a sequential, Stackelberg game, with the supplier as the leader and the retailer as the follower. Retailer's insufficient capital refers to the retailer's initial capital quantity satisfy $B < w^* E(Q_r)$, to obtain more profit, retailer accepts the deferred-payment mode provided by supplier. On the ordering stage, the retailer paid part payment B , and B/w products are obtained at wholesale price w , the payment for the remaining $E(Q_r) - B/w$ products is $wE(Q_r)-B$, the supplier promises retailer pay deferred at price $w+w\delta$ ($\delta \ge 0$) after the sale, then the expected profit functions in two channels are as follows:

$$E(\Pi_r)=(p_r-w)\frac{B}{w}+(p_r-w-\delta w)(E(Q_r)-\frac{B}{w})-tC(e)-h_r\int_{m_r}^{x}(x-u)f(u)du-s_r\int_{x}^{n_r}(u-x)f(u)du \quad \textbf{(8)}$$

$$E(\Pi_m)=(p_d-c)E(Q_d)+(w-c)\frac{B}{w}+(w+\delta w-c)(E(Q_r)-\frac{B}{w})-(1-t)C(e)$$
$$-h_m\int_{m_d}^{y}(y-u)g(u)du-s_m\int_{y}^{n_d}(u-y)g(u)du \quad \textbf{(9)}$$

Then we have the following theorem

Theorem 1 For the decentralized dual-channel supply chain with joint promotion and retailer's capital constraint, the retailer adopt deferred-payment mode with rate δ, the supply chain system exist optimal solution if (i) $\alpha\eta t>\frac{1}{2}$, (ii) $\eta t(\beta^2-2\alpha^2)+\alpha<0$, (iii) $\xi>0$.

Where $\xi=4\alpha\eta t(\alpha^2-\beta^2)(2\alpha\eta t-1)-\beta^2$. And

$$p_d{}^*=\frac{\alpha\beta\eta t(4\alpha\eta t-1)\rho+2\alpha^2\eta t(2\alpha\eta t-1)(1-\rho)}{\xi}A+\frac{\alpha\beta\eta t(4\alpha\eta t-1)}{\xi}\mu_r+$$
$$\frac{2\alpha^2\eta t(2\alpha\eta t-1)}{\xi}\mu_d-\left(\frac{\alpha\beta\eta t(\alpha-\beta)+\beta^2/2}{\xi}-\frac{1}{2}\right)c \quad \textbf{(10)}$$

$$w^*=\frac{1}{1+\delta}\left\{\frac{[\beta(1-\rho)+\eta t[\beta(2\alpha-\beta)+2\alpha(\alpha-\beta)(2\alpha\eta t-1)]]\rho+4\alpha\beta\eta t(\alpha\beta\eta t-1)}{\xi}A+\right.$$
$$\left.\frac{2\alpha^2\eta t(2\alpha\eta t-1)-\beta^2\eta t}{\xi}\mu_r+\frac{\beta(2\alpha\eta t-1)^2}{\xi}\mu_d+\frac{(\alpha^2-\beta^2)\eta t(4\alpha^2\eta t-\alpha+\beta)-\alpha^2\eta t(\alpha-\beta)-\alpha\beta}{\xi}c\right\} \quad \textbf{(11)}$$

$$y^*=G^{-1}(\frac{s_m}{h_m+s_m}) \quad \textbf{(12)}$$

$$p_r^*=\eta t\frac{\rho A+\mu_r+\beta p_d^*-\alpha w^*(1+\delta)}{2\alpha\eta t-1}+w^*(1+\delta) \quad \textbf{(13)}$$

$$e^*=\frac{\rho A+\mu_r+\beta p_d^*-\alpha w^*(1+\delta)}{2\alpha\eta t-1} \quad \textbf{(14)}$$

$$x^*=F^{-1}(\frac{s_r}{h_r+s_r}) \quad \textbf{(15)}$$

Proof. Please see the Appendix for proof.

Based on our results, we obtain the following propositions:

Proposition 1 The effect of traditional retail channel's demand uncertainty on supply chain's decision is determined by

$$\frac{\partial p_r{}^*}{\partial \mu_r}>\frac{\partial p_d{}^*}{\partial \mu_r}>0,\ \frac{\partial w^*}{\partial \mu_r}>0.$$

From Proposition 1, we know that the effect of traditional retail channel's demand uncertainty on retailer's pricing is greater than that of supplier, and the more of μ_r, the higher of retailer and supplier's pricing, and the higher of supplier's wholesale price of unit product to retailer.

Proposition 2 The effect of online channel's demand uncertainty on the supply chain's pricing decision is determined by

$$\frac{\partial p_d^*}{\partial \mu_d} > \frac{\partial p_r^*}{\partial \mu_d} > \frac{\partial w^*}{\partial \mu_d} > 0 .$$

It is observed that the effect of online channel's demand uncertainty on supplier's pricing is greater than that of supplier's unit product wholesale price to retailer and the retailer's pricing, and the greater of μ_d, the higher of supplier's wholesale price to retailer, and also the higher of retailer's pricing.

Proposition 3 The effect of traditional and online channels' demand uncertainty on the wholesale price of retailer is determined by

$$\frac{\partial w^*}{\partial \mu_r} > \frac{\partial w^*}{\partial \mu_d} > 0 .$$

From Proposition 3, It can be seen that the traditional and online channels' demand uncertainty are all have positive effects on the wholesale price, the greater of demand uncertainty, the higher of wholesale price of retailer, and the effect of traditional channel's demand uncertainty on wholesale price is greater than that of online channel.

Proposition 4 The effect of deferred-payment rate on supply chain's decision is determined by

$$\frac{\partial p_d^*}{\partial \delta} = \frac{\partial p_r^*}{\partial \delta} = 0 , \ \frac{\partial w^*}{\partial \delta} < 0 .$$

It can be seen from proposition 4 that the deferred-payment rate has no effects on the direct channel's sale price and the traditional channel's retail price, but it has effect on the wholesale price to retailer, and the greater of deferred-payment rate, the lower of wholesale price to retailer.

Proposition 5 The effect of promotion cost and the retailer's sharing proportion to promotion cost on the retailer's decision is given by

$$\frac{\partial e^*}{\partial \eta} < 0 , \ \frac{\partial e^*}{\partial t} < 0 .$$

Proposition 5 showed that the promotion cost and the retailer's sharing proportion had a negative effect on the retailer's promotion effort degree, the retailer's promotion effort degree is decreased with the promotion cost and the retailer's sharing proportion to promotion cost.

Centralized pricing strategy with joint promotion and capital constraint

In the centralized dual-channel supply chain, where the supplier and retailer are vertically integrated, the supplier determines the retail price p_r, promotion degree e and direct sale price p_d simultaneously to maximize the supply chain's total profit. In the deferred-payment mode, the supplier promises retailer pay deferred at rate δ, it indicated that supplier has sufficient fund for production, so the dual-channel supply chain's total profit is as follows:

$$E(\Pi)=(p_r - c)E(Q_r)+(p_d - c)E(Q_d) - C(e) - h_r \int_{m_r}^{x} (x-u) f(u)du - s_r \int_{x}^{n_r} (u-x) f(u)du$$
$$-h_m \int_{m_d}^{y} (y-u) g(u)du - s_m \int_{y}^{n_d} (u-y) g(u)du \tag{16}$$

So we have the following theorem:

Theorem 2 For the centralized dual-channel supply chain with joint promotion and retailer's capital constraint, the retailer adopt deferred-payment mode with rate δ, the supply chain system exist optimal solution if $\zeta = 2(\alpha^2 - \beta^2)\eta - \alpha > 0$, and

$$x_c^* = F^{-1}(\frac{s_r}{h_r + s_r}) \tag{17}$$

$$y_c^* = G^{-1}(\frac{s_m}{h_m + s_m}) \tag{18}$$

$$p_{rc}^{*}=\frac{[\beta(1-\rho)+\alpha\rho]\eta}{\zeta}A+\frac{\alpha\eta}{\zeta}\mu_r+\frac{\beta\eta}{\zeta}\mu_d+\frac{(\alpha^2-\beta^2)\eta-\alpha}{\zeta}c \tag{19}$$

$$p_{dc}{}^{*}=\frac{(2\alpha\eta-1)(1-\rho)+2\beta\eta\rho}{2\zeta}A+\frac{\beta\eta}{\zeta}\mu_r+\frac{2\alpha\eta-1}{2\zeta}\mu_d+\frac{(\alpha+\beta)[1-2\eta(\alpha-\beta)]}{2\zeta}c \tag{20}$$

$$e_c^{*}=\frac{\beta(1-\rho)+\alpha\rho}{\zeta}A+\frac{\alpha}{\zeta}\mu_r+\frac{\beta}{\zeta}\mu_d+\frac{\beta^2-\alpha^2}{\zeta}c \tag{21}$$

The proof is similar to Theorem 1, so we omit it.

According to our theorem 2, we obtain the following propositions:

Proposition 6 The effect of deferred-payment rate on the supply chain's decision is determined by

$$\frac{\partial p_{dc}{}^{*}}{\partial\delta}=\frac{\partial p_{rc}{}^{*}}{\partial\delta}=\frac{\partial e_c{}^{*}}{\partial\delta}=0\,.$$

From Proposition 6 we can see that the deferred-payment rate has no effects on the two channels' retail price and promotion degree, it means that in the centralized dual-channel supply chain with retailer's deferred-payment mode, retailer's capital constraint problem is the internal problem of system, which has no effects on the optimal pricing of supplier and retailer.

Proposition 7 The effect of traditional retail channel's demand uncertainty on the channel's pricing decision is greater than that of online channel, which is given by

$$\frac{\partial p_{rc}{}^{*}}{\partial\mu_r}>\frac{\partial p_{rc}{}^{*}}{\partial\mu_d}>0\,,\ \frac{\partial e_c{}^{*}}{\partial\mu_r}>\frac{\partial e_c{}^{*}}{\partial\mu_d}>0\,.$$

It is observed that that the two channels' demand uncertainty are all have effects on the retailer's optimal pricing and promotion degree from Proposition 7, and the influence of traditional retail channel's demand uncertainty on retailer's optimal pricing and promotion degree is greater than that of direct channel, and the greater of two channels' demand uncertainty, the higher of retailer's optimal pricing, and the higher of retailer's promotion degree.

Proposition 8 The effect of retail channel's demand uncertainty on the supplier and retailer's decision is given by

$$\frac{\partial p_{rc}{}^{*}}{\partial\mu_r}>\frac{\partial p_{dc}{}^{*}}{\partial\mu_r}>0\,.$$

It is observed that the effect of retail channel's demand uncertainty on retailer's pricing decision is greater than that of supplier from Proposition 8, and the greater of retail channel's demand uncertainty, the higher of retailer and supplier's optimal pricing.

Proposition 9 The effect of retailer's promotion cost on the retailer's decision is given by

$$\frac{\partial e_c{}^{*}}{\partial\eta}<0\,.$$

NUMERICAL EXAMPLES

In this section we perform a numerical analysis to verify our results and illustrate the effect of joint promotion and the retailer's capital constraint on the optimal pricing decisions for the dual-channel supply chain. It will complement our analytical results and provide us with more managerial insights.

In our example, it is assumed that the random demand of traditional channel $\varepsilon_r \sim U(0,4)$, the random demand of online channel $\varepsilon_d \sim U(0,6)$, other parameters in the supply chain system take in the following values:

$A=20$, $\rho=0.5$, $c=3$, $\alpha=0.3$, $\beta=0.1$, $h_r=4$, $s_r=8$, $h_m=3$, $s_m=6$, $\delta=0.05$, $\eta=7$, $t=0.5$.

Decentralized supply chain

According to the theoretical results of decentralized supply chain and parameter values mentioned above, we obtained $w^*=26.697$, $p_r{}^*=51.403$, $p_d{}^*=37.548$, $e^*=6.677$, and the retailer and supplier's inventory levels for uncertainty demand are $x^{*}=2.67$, $y^{*}=4$, respectively. The effect of two channels' uncertainty demand, deferred-payment rate, promotion cost and the retailer's sharing proportion of promotion cost on the channel's optimal pricing is as Figure1-Figure5, they are consistent with the theoretical analysis of Proposition1 to Proposition5.

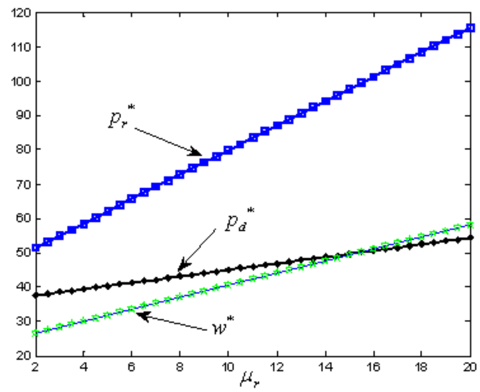


Figure 1: The influence of retail channel's uncertainty demand on pricing decision

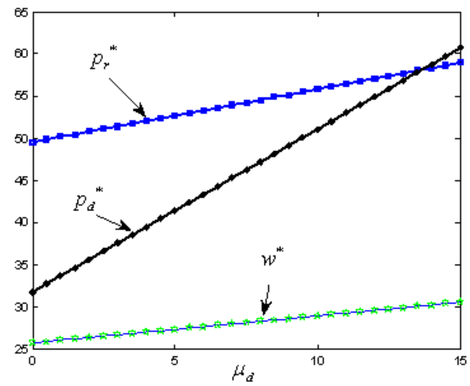


Figure 2: The influence of direct channel's uncertainty demand on pricing decision

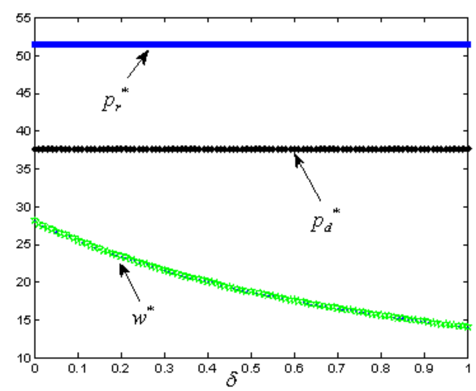


Figure 3: The influence of retailer's deferred payment rate on pricing

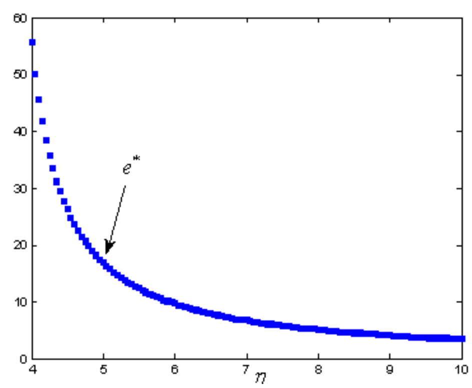


Figure 4: The influence of promotin cost on the decision retailer's promotion effort

Degree

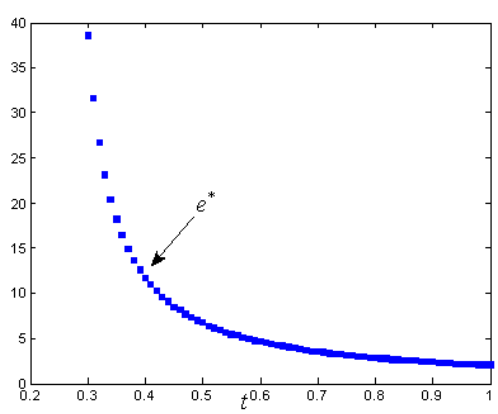


Figure 5: The influence of the retailer's sharing proportion for promotion cost on it's promotion effort

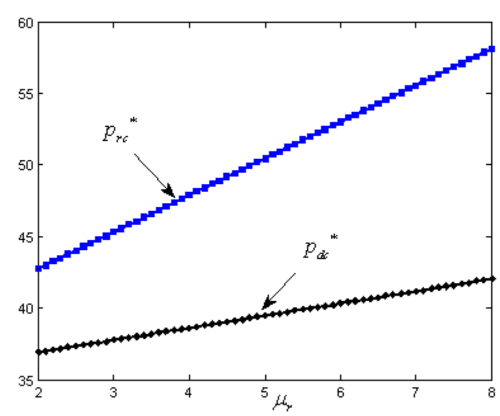


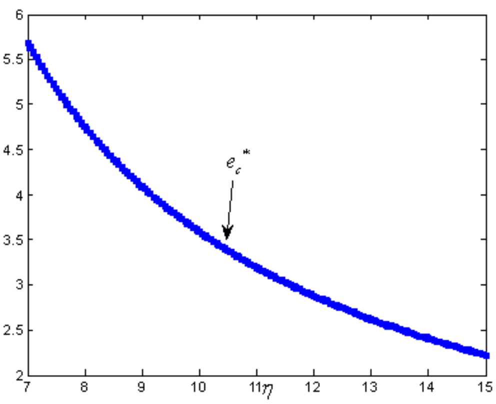
Figure 6: The influence of retail channel's uncertainty demand on centralized pricing decision

Centralized supply chain

According to the theoretical results of centralized supply chain and parameter values mentioned above, we obtained that $p_{rc}^{*}=42.781$, $e_{c}^{*}=5.683$, $p_{dc}^{*}=36.927$, and the retailer and supplier's inventory levels for uncertainty demand are

$x^* = 2.67$, $y^* = 4$, respectively. The effect of two channels' demand uncertainty and promotion cost on the optimal pricing is as Figure 6-Figure 8, they are consistent with the theoretical analysis of Proposition 6 to Proposition 9.

It can be seen from the above numerical analysis that the inventory levels for uncertainty demand of retailer and supplier are identical in centralized and decentralized case, but the total profit in centralized case ($E(\Pi)$=437.095) is greater than that ($E(\Pi_r)+E(\Pi_m)$=420.859) of decentralized one. So the supplier and retailer can consider the designing of contract for the coordination of supply chain, which will get a Pareto improvement on the profits of supplier and retailer.



Figrue 8: The retailer's proportion effort changing with the promotion cost

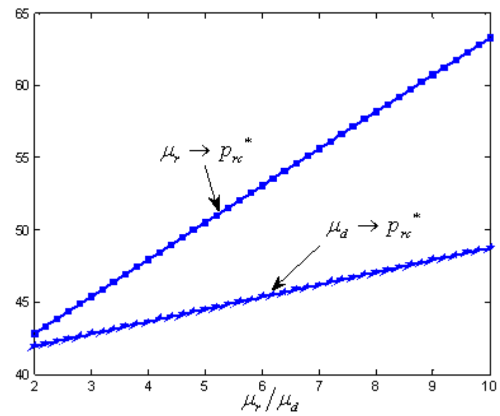


Figure 9: The influence of two channel's demand uncertainty on retailer's centralized pricing decision

APPENDIX

We solve the Stackelberg equilibrium solution of supply chain by inverse order method. Firstly, to maximize the retailer's profit, given the supplier's direct sale price p_d, wholesale price w, and the inventory level y, retailer determines the retail price p_r, the promotion degree e and inventory level x, the retailer's decision:

$$\max E(\Pi_r)=\max[(p_r - w)E(Q_r) - \delta(wE(Q_r) - B) - tC(e) - h_r\int_{m_r}^{x}(x-u)f(u)du - s_r\int_{x}^{n_r}(u-x)f(u)du] \quad \textbf{(A1)}$$

As (A1) can be divided into $(p_r - w)E(Q_r) - \delta(wE(Q_r) - B) - tC(e)$ and $-[h_r\int_{m_r}^{x}(x-u)f(u)du + s_r\int_{x}^{n_r}(u-x)f(u)du]$ two parts, and the second part is only relate to inventory level x, so find the optimal value of retail price p_r, the promotion degree e and inventory level x on $E(\Pi_r)$ respectively, and can obtain the retailer's optimal decisions p_r^*, e^* and x^*, as

$$\frac{\partial^2 E(\Pi_r)}{\partial p_r^{\,2}} = -2\alpha_r < 0\ , \quad \frac{\partial^2 E(\Pi_r)}{\partial e^2} = -\eta t < 0\ , \quad \frac{\partial^2 E(\Pi_r)}{\partial x^2} = -(h_r + s_r)f(x) < 0$$

So there exist maximum on $E(\Pi_r)$, according the FOC of $E(\Pi_r)$, We obtained (15) and

$$p_r^* = \frac{1}{2\alpha}(\rho A + \beta p_d + \mu_r + e + \alpha w(1+\delta)) \quad \textbf{(A2)}$$

$$e^* = \frac{p_r - w(1+\delta)}{\eta t} \quad \textbf{(A3)}$$

Substituting (A2) and (A3) into (3) and (4), and obtained:

$$E(Q_r)=\frac{\alpha\eta t}{2\alpha\eta t - 1}(\rho A + \beta p_d + \mu_r) + \frac{\alpha w(1+\delta)}{2\alpha\eta t - 1} \quad \textbf{(A4)}$$

$$E(Q_d)=[\frac{\beta\eta t}{2\alpha\eta t-1}\rho+(1-\rho)]A+(\frac{\beta^2\eta t}{2\alpha\eta t-1}-\alpha)p_d+\frac{\beta\eta t}{2\alpha\eta t-1}\mu_r+\mu_d+\beta w(1+\delta)\frac{\alpha\eta t-1}{2\alpha\eta t-1} \quad \textbf{(A5)}$$

Substituting (A4) and (A5) into (9), and find the first partial derivatives on $E(\Pi_m)$ to direct sale price p_d, wholesale price w, and the inventory level y, respectively, and let them equal to 0, so we obtain the game equilibrium strategy of supplier. As (9) can be divided into $(p_d-c)E(Q_d)+(w-c)B/w$ $+(w+\delta w-c)(E(Q_r)-\frac{B}{w})-(1-t)C(e)$ and $-h_m\int_{m_d}^{y}(y-u)g(u)du-s_m\int_{y}^{n_d}(u-y)g(u)du$ two parts, which are the functions of (p_d,w) and inventory level y, respectively. And

$$\frac{\partial^2 E(\Pi_m)}{\partial p_d{}^2}=\frac{2\beta^2\eta t}{2\alpha\eta t-1}-2\alpha<0\,,\ \frac{\partial^2 E(\Pi_m)}{\partial y^2}=-(h_m+s_m)g(y)<0\,,\ \frac{\partial^2 E(\Pi_m)}{\partial w^2}=-\frac{2\alpha^2\eta t(1+\delta)^2}{2\alpha\eta t-1}<0$$

So there exist maximum on $E(\Pi_m)$, then according the FOC of $E(\Pi_m)$ can get (10), (11) and (12).

In the following, to prove $E(\Pi_m)$ reaches maximum at (p_d^*,w^*,y^*), we just prove when $y=y^*$, $E(\Pi_m)$ reaches maximum at (p_d^*,w^*), as $\frac{\partial^2 E(\Pi_m)}{\partial p_d{}^2}=\frac{2\beta^2\eta t}{2\alpha\eta t-1}-2\alpha<0$, its Hessian matrix:

$$|H|=\begin{vmatrix}\frac{\partial^2 E(\Pi_m)}{\partial p_d{}^2}\Big|_{(p_d^*,w^*)} & \frac{\partial^2 E(\Pi_m)}{\partial p_d\partial w}\Big|_{(p_d^*,w^*)}\\ \frac{\partial^2 E(\Pi_m)}{\partial w\partial p_d}\Big|_{(p_d^*,w^*)} & \frac{\partial^2 E(\Pi_m)}{\partial w^2}\Big|_{(p_d^*,w^*)}\end{vmatrix}=\frac{(1+\delta)^2\xi}{(2\alpha\eta t-1)^2}>0$$

So $E(\Pi_m)$ reaches maximum at (p_d^*,w^*,y^*).

Substituting (10) and (11) into (A2) and (A3), and can obtain formula (13) and (14).

CONCLUDING REMARKS

Joint promotion and capital constraint is a very important issue in dual-channel supply chain management, this paper examines the pricing decision in a dual-channel supply chain with one supplier and one retailer under joint promotion and retailer's capital constraint. And draws the conclusion that the demand uncertainty of two distribution channels, deferred-payment rate, promotion cost and the retailer's sharing proportion of promotion cost etc, are all have certain influence relation on the pricing strategies of supplier and retailer. Furthermore, in the decentralized supply chain, the effect of traditional retail channel's demand uncertainty on retailer's pricing is greater than that of supplier; and the more of uncertainty demands in traditional channel, the higher of retailer and supplier's pricing, and the higher of supplier's wholesale price of unit product to retailer; the greater of uncertainty demands in direct channel, the higher of supplier's wholesale price to retailer, and also the higher of retailer's pricing; the traditional and online channels' demand uncertainty are all have positive effects on the wholesale price; the deferred-payment rate has no effects on the direct channel's sale price and the traditional channel's retail price, but it has effect on the wholesale price to retailer; the promotion cost and the retailer's sharing proportion had a negative effect on the retailer's promotion effort degree, the retailer's promotion effort degree is decreased with the promotion cost and the retailer's sharing proportion to promotion cost. In the centralized supply chain, the two channels' demand uncertainty are all have effects on the retailer's optimal pricing and promotion degree; the effect of retail channel's demand uncertainty on retailer's pricing decision is greater than that of supplier. Numerical experiment has verified the effectiveness of the conclusions.

There are several directions for further analysis that will achieve a better understanding of dual-channel supply chain. For instance, one may present a revenue sharing contract, which can relieve the channel conflict, realize the win-win outcome between supplier and retailer, and get a Pareto improvement on the profits of two sides, in addition, it would be interesting to examine the supply chain's unite decision of product pricing under joint promotion and retailer's capital constraint, and it is insightful to consider how the supplier determine deferred payment rate and joint promotion strategies to realized the coordination of supply chain system under the condition that the system is composed of more retailers and one supplier with different retailers have different capital constraints.

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