A Partial Information Sharing Incentive Pricing Model with Demand Uncertainty in Dual-Channel Supply Chain

Abstract. In this paper the information-sharing incentive problem with uncertain demand is studied, one manufacturer with electronic direct sales and two retailers in dual-channel supply chain under the electronic commerce environment. The partial information sharing incentive pricing model with demand uncertainty in dual channels is built, which is based on the price discrimination strategy to prompt retailers to share their private demand information. By the optimal solution and game equilibrium analysis to the partial information sharing incentive model, the following results are drawn from the partial information sharing incentive model in dual-channel supply chain: the valid conditions of partially sharing uncertain demand information, the stable equilibrium conditions of the price discrimination strategy, and the coexistence conditions of coordinating between traditional channels and electronic channels.

Keywords: Demand Uncertainty, Dual-channel, Partial Information Sharing

Introduction

With the recent rapid development of e-commerce, the channel structure of the supply chain has undergone great changes. Nowadays, direct sales channels have been reconstructed in internet by many companies, they coexist with retail channels, so the coordination and conflict of the resulting hybrid dual-channel supply chain becomes a new research focus. Tsay et al (2000) proposed the coordination mechanism for dynamic channel structure with price and service competition [1]. Chiang et al (2003) studied strategy analysis of dual-channel design in the supply chain, and analyzed the basic framework and dynamic coordination mechanism of the direct sales channels and traditional channels [2]. Yan et al (2007) studied the dual-source channel coordination problem in the supply chain based on supply chain double source master-slave response model under the electronic market environment [3]. Xing et al (2008) studied the optimal strategy of suppliers and retailers by the game analysis of supply and demand in B2B e-market environment, and drew a conclusion by numerical analysis that retailers benefit from price volatility increasing in B2B e-market [4]. Xiong et al (2007) studied the channels coordination problem based on the impact of dynamic pricing on different contracts in the network environment [5]. Pu et al studied the impact of direct sales model on existing strong retail channels in network environment [6]. Guo et al (2008) analyzed dual channel’s conflict and coordination in the electronic market [7]. Chen et al (2006,2008) studied respectively the price competition between e-commerce retailers and traditional retailers and the two-channel retailer’s pricing strategy in the Internet environment [8]-[9]. However, these researchers did their work under the assumption of complete information, and they mainly studied channel conflict and price problem in dual-channel supply chain. They did not pay attention to the asymmetric information between manufacturers and retailers in dual-channel supply chain so that they did not consider information sharing impacts on supply chain in dual-channel.

Yao etc. firstly researched on a series information sharing problem in dual-channel supply chain based on value adding. Yao etc. (2005a) studied the retailers’ wholesale price in hybrid channel structure, and get the optimal wholesale price based on Stackelberg and Bertrand competition [10]. Meanwhile, Yao etc. (2005b) designed a direct channel supply chain model with return policy, and analyzed the impact of sharing demand forecast information in their model, and finally found that information sharing was profitable for both manufacturers and retailers [11]. Yao etc. (2008) also found that retailers are willing to share their private information when retailers with value-added are in hybrid channels high-tech supply chain [12]. Chen et al (2008) studied the impact of service competition for dual-channel sales [13]. Ai and Tang etc. studied the performance problems of information sharing between retail channels and manufacturers dominated electronic direct sale channels, and got the results that the information sharing performance is different from the traditional channels structure [14]. From the viewpoint of revenue sharing co-operation mechanism, Chen and Ai (2008) studied the information sharing problem of traditional channels and e-channels and analyzed the impact of market competition, market risks, the potential market size, and the ability of information predicting on dual-channel information sharing and revenue sharing strategy selection [15]. It is obvious that the retailers’ information sharing in the mix dual-channel has become the latest hot point. But they only discussed the impact of information sharing from the view of the centralized and decentralized supply chain, rather than did research and design information sharing incentive mechanisms. Generally, information sharing can be divided into complete information sharing and partial information sharing in terms of the number of enterprises involved. In the above study, they regarded information sharing as complete information sharing and no information sharing [11]-[12], but actually, it’s is very common that only part of enterprises are participating in information sharing. Although Yao et al (2008) considered the supply chain system consisted of one manufacturer M and two retailers (R₁ and R₂), and they also considered the case of partial information sharing, but they studied retailer’s cost information sharing in dual-channel [16]. In this paper we shall probe a partial information sharing model with demand uncertainty, and design information-sharing incentive model using price discrimination strategy.

Information sharing in supply chain can improve the profits of manufacturers and wholesalers as well as the overall function of the supply chain, but it can not improve the performance of the retailers [17]-[18]. In this study, assuming that the effect of information sharing in the dual-channel is the same as in the physical supply chain, our study would focus on three aspects (1) sharing demand
information, considering the impact of demand uncertainty private information on supply chain performance; (2) partial information sharing, part of the retailers participating in information sharing; (3) encouraging information sharing by price discrimination strategy 18,19, the wholesale price for retailers participating in information sharing is lower than those for retailers not participating in information sharing. In this paper, the demanded information-sharing incentive mechanism is designed to stimulate retailers to actively share their private demand uncertain information, which is based on partial information sharing and price discrimination strategies in a dual-channel supply chain with electronic direct marketing. Therefore, the said mechanism takes into account two channel supply chains of one manufacturer and two retailers, thinking about how to coordinate manufacturers’ electronic direct marketing and retailers’ sale channels to develop the optimal wholesale price when the manufacturers dominate, encourages retailers to actively share demand information, improves the validity of the entire supply chain, so as to get the optimal game equilibrium that all retailers share demand information.

2 The partial information sharing incentive model
This paper considers the supply chain system with one manufacturer M and two retailers (R1 and R2), and builds a incentive model that part of retailers participate in information sharing with electronic direct marketing channels in accordance with retailers sharing the uncertain demand information or not, as shown in Figure 1. In the model, customers can buy from the two retailers or purchase directly from manufacturer’s electronic direct marketing channels. Retailers offer value-added services to customers who are independent of each other, and there isn’t level competition between them. But customers transfer freely between retail channels and direct sales channels due to price-sensitivity, acquisition costs, access to opportunities, buying habits and other factors. In the model, manufacturers use price discrimination strategy to encourage retailers to participate in information sharing, to be specific, when retailer R1 participates in information sharing and retailer R2 does not participate in information sharing, in order to reward retailer R1 to share information, the manufacturers offer retailer R1 at a lower wholesale price than what they would offer to retailer R2. The specific work structure of the model is three-stage decision sequence. First of all, manufacturers choose whether to work structure of the model is three-stage decision sequence. First of all, manufacturers choose whether to participate in information sharing, then manufacturers make their own selling prices with respect to profit maximization rule; Second, retailers decide whether to share their private demand information; Finally, the retailers come to decide their own sales prices with respect to profit maximization and order, then manufacturers meet the requirements of orders. Assume the notations in the model as follow: \( x_1 \) is the profits of retailer R1, \( x_2 \) is the profits of retailer R2, \( \pi_1 \) is the profits of manufacturer M; \( d_1 \) is the demand of retailer R1, \( d_2 \) is the demand of retailer R2, \( \theta \) is the direct sale demand of manufacturer M; \( p_1 \) is retailer R1’s sale price, \( p_2 \) is retailer R2’s sale price, \( p_w \) is the direct sale price of manufacturer M; \( v_1, v_2 \) are respectively the incremental value of retailer R1 and R2, \( c(v_i) \) is the cost of retailer R1 providing incremental value \( v_i \), \( c(v_2) \) is the cost of retailer R2 providing incremental value \( v_2 \); \( w_1 \) is the wholesale price of retailer R1 when sharing information, \( w_2 \) is the wholesale price of retailer R2 when not sharing information; \( t \) is the signal size that reflects the uncertainty of the market demand, whose value depends on market demand. \( t \) is subject to normal distribution with mean 0 and variance \( \sigma^2_i \), that is, \( t \sim N(0, \sigma^2_i) \). \( t \) may be negative, \( i = 1,2,3 \). Optimal values for all parameters shall be marked by the top right mark “**”.

![Fig.1. The Partial Information Sharing Incentive Pricing Model](image)

Assume that the demand function of goods meet linear relationship, the dual-channel supply chain system with value added services and channel transfer, the demand functions of retailers and manufacturers are as follows. The demand function of retailer R1 participating in information sharing:
\[
d_1 = D(p_1, p_1, v_1) = a_1 - b_1 p_1 + t_1 + \beta_1 v_1 + \alpha_1 p_1 + v_1 - p_1
\]
The demand function of retailer R2 not participating in information sharing:
\[
d_2 = D(p_2, p_2, v_2) = a_2 - b_2 p_2 + t_2 + \beta_2 v_2 + \alpha_2 p_2 + v_2 - p_2
\]
The demand function of manufacturer direct sale channel:
\[
d_w = D(p_w, p_w, v_w) = a_w - b_w p_w + t_w + \beta_w v_w + \alpha_w p_w + v_w - p_w
\]

3 Model Solution
Model solution ideas: solving the model by reverse analysis method, while for uncertainty of market information \( t_i \), if the parties do not have a \( t_i \), then the corresponding side of the model uses 0 (the expectations of \( t_i \)). The model solution satisfies the following expression:
\[
\max_{p_1, p_2} \pi_1 = w_1 d_1 + w_2 d_2 + p_1 d_1
\]
max \tau_2 = (p_2 - c(v_2) - w_2)d_2

3.1 The optimal decision of retailer R1 participating in information sharing
Property 1  If $2\eta(b + \theta)d_1 > [(\beta + \theta) - \eta(b + \theta)v_1]^2$, then the retailer R1’s profit $\tau_2$ is concave function of the retail price $p_1$ and service add-value $v_1$.
Proof: Due to the length of paper, the proofs of Properties and propositions are omitted in this paper.

By solving the retailer’s decision problem, we can get the following Proposition 1.

Proposition 1  If $2\eta(b + \theta)d_1 > [(\beta + \theta) - \eta(b + \theta)v_1]^2$, in partial information sharing incentive model of the dual-channels supply chain with demand uncertainty, when retailer R1 participates in information sharing and the manufacturer offers a wholesale price $w_1$, the optimal equilibrium decision of retailer R1’s sale price $p_1$ and service add-value $v_1$ is:

$$p_1^* = \frac{3(\theta + \beta)^2 + a_1 + \theta p_1 + t_1 + (b + \theta)v_1}{2(b + \theta)} \quad v_1^* = \frac{\theta + \beta}{\eta(b + \theta)}$$

3.2 The optimal decision of retailer R2 not participating in information sharing
As retailer R2 and retailer R1 are mutual independent and equal, we can get property 2 with the same reason.

Property 2  If $2\eta(b + \theta)d_1 > [(\beta + \theta) - \eta(b + \theta)v_1]^2$, then the retailer R2’s profit $\tau_2$ is concave function of the retail price $p_2$ and service add-value $v_2$.

By solving the retailer R2’s decision problem, we can get the following Proposition 2.

Proposition 2  If $2\eta(b + \theta)d_1 > [(\beta + \theta) - \eta(b + \theta)v_1]^2$, in the partial information sharing incentive model of dual-channels with demand uncertainty, when retailer R2 doesn’t participate in information sharing, and the manufacturer offers a wholesale price $w_2$, the optimal equilibrium decision of retailer R2’s sale price $p_2$ and service add-value $v_2$ is:

$$p_2^* = \frac{3(\theta + \beta)^2 + a_2 + \theta p_2 + t_2 + (b + \theta)v_2}{2(b + \theta)} \quad v_2^* = \frac{\theta + \beta}{\eta(b + \theta)}$$

3.3 The optimal decision of manufacturer
Property 3  In the partial information sharing incentive model of dual-channels with demand uncertainty, the manufacturer’s profit function is concave function of manufacturer’s direct sale price $p_3$, wholesale price $w_1$ of retailers participating in information sharing while wholesale price $w_2$ of retailers not participating in information sharing.

By solving manufacturer’s decision problem, we can get the following Proposition.

Proposition 3  In partial information sharing incentive model of dual-channels with demand uncertainty, the optimal equilibrium decision of the manufacturer’s direct sale price $p_3$, the wholesale price $w_1$ of retailers participating in information sharing, the wholesale price $w_2$ of retailers not participating in information sharing is:

$$p_3^* = \frac{a_1 + t_1 + t_2 + \theta(a_1 + a_2 + a_3 + 2t_1 + t_2) + \theta^2(a_1 + a_2 + a_3 + 2t_1 + t_2)}{2(b + 3\theta)} \quad w_1^* = \frac{a_1 + t_1 + t_2 + \theta(a_1 + a_2 + a_3 + 2t_1 + t_2) + \beta \theta (a_1 + a_2 + a_3 + 2t_1 + t_2)}{2b(b + \theta)(b + 3\theta)} \quad w_2^* = \frac{a_1 + t_1 + t_2 + \theta(a_1 + a_2 + a_3 + 2t_1 + t_2) + \theta^2(a_1 + a_2 + a_3 + 2t_1 + t_2)}{2b(b + \theta)(b + 3\theta)}$$

Substitute $w_1$ and $w_2$ of proposition 3 into proposition 1 and proposition 2 respectively, we can get proposition 4.

Proposition 4  In the partial information sharing incentive model of dual-channels with demand uncertainty, when retailer R1 participates in information sharing and retailer R2 doesn’t participate in information sharing, their optimal equilibrium decisions of retail price and service added-value are respectively:

$$p_1^* = \frac{3a_1 + 2t_1 + \theta(a_1 + a_2 + a_3 + 2t_1 + t_2)}{2(b + \theta)(b + 3\theta)} \quad v_1^* = \frac{\theta + \beta}{\eta(b + \theta)}$$
$$p_2^* = \frac{3a_2 + 2t_2 + \theta(a_1 + a_2 + a_3 + 2t_1 + t_2)}{2(b + \theta)(b + 3\theta)} \quad v_2^* = \frac{\theta + \beta}{\eta(b + \theta)}$$

We can get the following properties from proposition 1, 2, 3 and 4.

Property 4  The decision-making of retailers’ creating added-value is only related to cost coefficient $v_1$ of retailers’ producing added-value, price volatility coefficient $b$, value-added volatility coefficient $\beta$ and channel diffusion intensity, it has nothing to do with demand uncertainty coefficient $t$.

Property 5  The decision-making of retailers’ creating added-value are independent of information-sharing decision, the final added-value of retailers are equal.

3.4 The profit distribution mechanism
Substitute the optimal equilibrium solution of $w_1$, $w_2$, $p_3$, $p_1$, $v_1$ and $v_2$ from Proposition 3 and Proposition 4 into the profit functions of retailers and manufacturer, we can get optimal profit $\pi^*$, $\pi^*_1$, $\pi^*_2$ and $\pi^*_3$ of retailer R1 involved in information sharing, retailer R2 not involved in information sharing and manufacturer’s direct channels respectively.

Proposition 5  In partial information sharing incentive model of mix dual-channels with demand uncertainty, the profit of manufacturer, retailer R1 involved in information sharing, and retailer R2 not involved in information sharing respectively are:

$$\pi^*_1 = \left(2\beta + \beta^2 + \frac{(\beta + \theta)^2(\beta + \theta)(b + 3\theta)}{16b(b + \theta)} \right)$$
$$\pi^*_2 = \left(2\beta + \beta^2 + \frac{(\beta + \theta)^2(\beta + \theta)(b + 3\theta)}{16b(b + \theta)} \right)$$
$$\pi^*_3 = \left(2\beta + \beta^2 + \frac{(\beta + \theta)^2(\beta + \theta)(b + 3\theta)}{16b(b + \theta)} \right)$$
$$\pi^*_1 = \left(2\beta + \beta^2 + \frac{(\beta + \theta)^2(\beta + \theta)(b + 3\theta)}{16b(b + \theta)} \right)$$
$$\pi^*_2 = \left(2\beta + \beta^2 + \frac{(\beta + \theta)^2(\beta + \theta)(b + 3\theta)}{16b(b + \theta)} \right)$$
$$\pi^*_3 = \left(2\beta + \beta^2 + \frac{(\beta + \theta)^2(\beta + \theta)(b + 3\theta)}{16b(b + \theta)} \right)$$

We can get the following properties:

Property 5  The decision-making of retailers creating added-value are independent of information-sharing decision, the final added-value of retailers are equal.

Property 6  The decision-making of retailers creating added-value is only related to demand uncertainty coefficient $t$.

Property 7  The decision-making of retailers creating added-value are independent of information-sharing decision.

Property 8  The decision-making of retailers creating added-value is only related to demand uncertainty coefficient $t$.

Property 9  The decision-making of retailers creating added-value are independent of information-sharing decision.
Where \( l = (\beta + \theta)(3\beta - \theta) + 4 \beta \theta^2 + b^2(\beta + \theta) \), \( l = a_i + a + t_1 \), \( k = a_i + t_1 + t_2 \), \( k = (b + \theta)(4b - 3\beta - \theta) \), \( m = 2(b - \beta)\beta + \theta \).

4 Model analysis and discussion

In our partial information sharing incentive pricing model with demand uncertainty in dual-channel supply chain, it should be sure to meet specific conditions to encourage retailers to share private information by using price discrimination strategy. Following, we are going to analyze the validity of partial information sharing pricing incentive mechanism, the stable equilibrium conditions of price discrimination strategies, and coordination mechanism between mix channels.

4.1 The validity of partial information sharing pricing incentive mechanism

In our partial information sharing incentive pricing model with demand uncertainty in dual-channel supply chain, in order to make partial information sharing pricing incentive mechanism effective, we have to make the optimal profits the retailer R1 involved in information sharing and retailer R2 not involved in information sharing satisfy \( \pi^* > \pi^* \). Otherwise, retailer R1 might be unwilling to share their private uncertain demand information. By Proposition 5, there is

\[
\pi^* - \pi^* > 0,
\]

Further to simplify, there is

\[
\left( a_i - a_i - t_1 - 2t_2 \right)^2 + \left( a_i + t_2 \right)^2 - \left( a_i + 2t_2 \right)^2 > 0.
\]

So to make partial information sharing pricing incentive mechanism effective, it must meet the conditions that above expression is greater than 0, that is Proposition 6.

Proposition 6 Conditions of validity of partial information sharing pricing incentive mechanism is

\[
\left( a_i - a_i - t_1 - 2t_2 \right)^2 + \left( a_i + t_2 \right)^2 - \left( a_i + 2t_2 \right)^2 > 0.
\]

From the validity condition of partial information sharing pricing incentive mechanism, we can get Property 6.

Property 6 The validity condition of partial information sharing incentive mechanism is related with basic demand and uncertain demand of retailers as well as with cost coefficient \( \eta \) of retailers’ creating added-value, price volatility coefficient \( \beta \), added -value fluctuations coefficient \( \beta \) and channel diffusion intensity \( \theta \).

4.2 The stable equilibrium condition of price discrimination strategy

For \( w_1^*w_2^* \) of the price discrimination strategy, in our partial information sharing incentive pricing model with demand uncertainty in dual-channel supply chain, transform the equations of \( w_1^* \) and \( w_2^* \), and simplify them, we get:

\[
w_1^* - w_2^* = \frac{a_i - a_i - t_1 + t_2}{2(b + \theta)} - \frac{\theta^2(a_i + t_1 + t_2)}{2(b + \theta)(b + 3\theta)} < 0.
\]

That is the stable equilibrium condition of price discrimination strategy, Property 7.

Proposition 7 In partial information-sharing incentive model of dual-channel supply chain with demand uncertainty, condition of stable equilibrium of price discrimination strategy is to meet the following inequality

\[
a_i - a_i - t_1 + t_2 < 0.
\]

From condition of stable equilibrium of price discrimination strategy, we can get Property 7.

Property 7 The condition of stable equilibrium of price discrimination strategy is related with basic demand of retailers and manufacturers, and uncertain demand of retailers participating in information-sharing and manufacturer’s direct sale as well as price volatility coefficient \( \beta \) and channel diffusion intensity \( \theta \), while it isn’t related with uncertain demand of retailers participating in information-sharing and added -value fluctuations coefficient \( \beta \).

4.3 Coordination between mix channels

For dual-channel model with the mix-coexistence of manufacturer’s electronic direct marketing and retailers’ sale, mix dual-channels can co-exist without conflict in the real world only when retail prices of retailers with value-added services and direct sale prices of manufacturer’s electronic direct channel meet the following conditions. That is \( p_1 - p_2 \geq 0 \) or \( p_1 - p_2 \geq 0 \) otherwise, the manufacturer’s electronic direct marketing is no longer necessary.

Substitute the optimal solution of \( p_1, p_2, p_3 \) into them and simplify them, we get the basic coordination conditions between dual-channel, which is Proposition 8.

Proposition 8 For the coordination of mix dual-channel with demand uncertainty, the basic conditions that allow manufacturer’s electronic direct channel to exist are:

\[
6a_i + 2t_1 + 4\left(a_i + t_2\right) - 4\theta(a_i + a_i - t_1) + \frac{(\beta + \theta)(7b + 15b + 13\beta + 2d)}{(b + 3\theta)} \geq 0
\]

Thus, the manufactures electronic direct sale exist, in contrast, if manufacturer’s electronic direct sale exist, in contrast, if manufacturer’s electronic direct sale exist already exists, only when retail prices and added-value of retailers with value-added services as well as manufacturer’s electronic direct sale prices meet the same conditions, mix dual-channel can coexist without conflict in reality; Otherwise, there would be no need for retailers because retailers wouldn’t create the extra added-value. Substitute the optimal solution of \( p_1, p_2, p_3 \) into the above inequalities and simplify them, we can get Proposition 9.

Proposition 9 The basic coordination conditions to allow retailers with value-added services exist in dual-channel supply chain with demand uncertainty are:

\[
(\beta + \theta)(8b^2 - 7b + + 17b + 13\beta + 11\beta^2) + \frac{4a_i + 4\theta(a_i + t_1) - 6a_i + 2t_1}{(b + \theta)(b + 3\theta)} - \frac{6a_i - 4t_1 - 4\theta(a_i + t_1)}{(b + \theta)(b + 3\theta)} \geq 0
\]

Proposition 8 and Proposition 9 form coordination conditions for mix dual-channel, which allow retailers with value-added services and manufacturer’s electronic direct sale channels co-exist in the dual-channel supply chain. They depend on and compete with each other to create value for benefits maximizing of the dual-channel supply chain.
5 Conclusion

In this paper the information-sharing incentive problem with uncertain demand is studied. We build the partial information sharing incentive pricing model with demand uncertainty in dual channels, then analyze and get the validity of partial information sharing pricing incentive mechanism, the stable equilibrium conditions of price discrimination strategies, and coordination mechanism between mix channels.

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