OPTIMAL DECISIONS FOR A DUAL-CHANNEL SUPPLY CHAIN UNDER INFORMATION ASYMMETRY

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ABSTRACT. We discuss the optimal pricing and production decisions in a channel supply chain under symmetric and asymmetric information cases. We compare the optimum policies between the asymmetric information and the full information cases. We analyze the effect of the reseller’s cost information on the profits of the partners. We find that information asymmetry is beneficial to the reseller, but is inefficient to the manufacturer and the whole supply chain. The information value increases with uncertainties arising from the reseller’s cost structure. The dual-channel supply chain can share information and achieve coordination, if the lump-sum side payment from the manufacturer can make up the loss of the reseller due to sharing information. Finally, the effectiveness of the proposed models is verified by numerical examples.

1. Introduction. Recently, as a result of the development of web technology and the third-party logistics firms such as FedEx and UPS, many upstream manufacturers (such as Dell, Hewlett Packard, Lenovo and Haier) have started selling products directly to customers via on-line stores, catalog sales, and factory outlets [6]. Manufacturers may sell their products directly and indirectly through the other channels such as distributors, wholesalers and retailers. This phenomenon is often referred to as supplier encroachment [17]. A typical example of supplier encroachment is that of Lenovo. Lenovo has many distributors in the world, but also owns the Lenovo online store. Therefore, consumers can either shop online, or purchase goods in a

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store. The direct channel helps Lenovo save cost, increase sale revenue and expand new market segments [9]. The direct channel has a great impact on customers’ purchase patterns. Nowadays, customers increasingly prefer to go shopping online, in order to save transportation cost and time or because of the generous return policy. The traditional indirect channel is focused on those customers who like buying products in store or who have difficulties in surfing the Internet like in some rural areas. However, the supplier encroachment has created a conflict between direct and indirect channels due to the price competition and operational approaches [9]. Methods of improving the performance of supplier encroachment in a supply chain have been an important topic for both academic researchers and practitioners [11]. Both suppliers and resellers can benefit from supplier encroachment, if double marginalization can be mitigated under some conditions [1] or when complete information is available in the supply chain. In other words, information structure may influence the effects of supplier encroachment [17]. In the existing literature, it is often assumed that the information structure is symmetric in the supply chain. This means that supplier encroachment can mitigate double marginalization when the supplier reduces the wholesale price, affecting the reselling price subsequently [1].

However, in practice, obtaining the complete information about each channel may be difficult or impossible in the planning period for hi-tech products having a short life-cycle [18]. Asymmetric cost information is very common in supply chain and hence is worth attention [18]. In this paper, we focus on large manufacturers (for example, computer industries) and relatively smaller resellers. To be specific, the manufacturer has sufficient power to set the direct and wholesale prices, while the resellers can decide the final market price. The price set by a reseller is asymmetric information in some value-added services (such as computer radiator-fan, computer cleaning packages, or computer bag). Then the final product is sold as a package to customers in the market [18]. The raw material and labor costs of the final product in the indirect channel are a reseller’s private information. The existing literature has hardly addressed the issue of a dual-channel supply chain after supplier encroachment when the cost information is asymmetric. Therefore, we are motivated to consider the following questions: 1) what is the effect of cost information asymmetry on the partners and the entire dual-channel supply chain? 2) How to coordinate a dual-channel supply chain? The main purpose of this paper is to investigate the effect of cost information asymmetry on the optimal policies in a dual-channel supply chain.

The contributions of this study are threefold. Firstly, we model the optimal policies in a dual-channel supply chain under full information as well as under asymmetric information cases. Secondly, we compare the optimal policies of the dual-channel supply chain between full information and asymmetric information cases. Thirdly, we investigate the value of the information by comparing the profit differences between the asymmetric information and the full information cases.

We have some interesting observations. Firstly, the asymmetric information does not change the direct price and the direct price is independent of a reseller’s cost structure. However, the indirect channel price and wholesale prices are higher in the full information case. The reselling and the whole demands decrease but the direct channel demand increases when changing from an asymmetric information case to a full information case. Secondly, information asymmetry is beneficial to the reseller, resulting in inefficiency to the manufacturer and the whole supply chain.
Thirdly, the profits of the partners and the entire supply chain would be improved if the reseller’s cost information is shared. The reseller is willing to share the cost information if the lump-sum side payment offered by the manufacturer can make up the reseller’s profit loss due to sharing information.

The remainder of this paper is organized as follows. Section 2 contains a brief literature survey. In Section 3, we analyze the modeling framework. In Section 4, we discuss the optimal policies with full information. In Section 5, we analyze the optimal policies with asymmetric information. In Section 6, we discuss the value of information. In Section 7, some numerical examples are presented. In Section 8, concluding remarks are made.

2. Literature review. This paper studies the intersection of supplier encroachment, supply chain coordination and asymmetric information. Thus, literature related to supplier encroachment, supply chain coordination and asymmetric information is reviewed and summarized in this section.

Over the past few years, the effects of supplier encroachment have been well studied in the marketing and supply chain management literature. In [11], the authors examine a price-setting game between a manufacturer and its independent retailer, based on the dual channel consumer choice model. They have found that the manufacturer is more profitable, even though no sales occur in the direct channel. In [2], the consequences of competitive stocking between a manufacturer and a reseller in a multichannel distribution system are examined. Also, the coordination mechanisms that eliminate the channel inefficiency are designed, in order to achieve the optimal supply chain profit. In [22], the optimal pricing model is built based on the game theory. In the pricing model, the manufacturer faces competition between an indirect channel and a Web-based channel. In [8], the authors investigate the service competition in a supply chain, involving the supplier encroachment that is based on consumer channel choice behavior. In [10], the authors investigate the impact of customers’ substitution on product availability and channel efficiency, when a supplier encroaches on the selling channel. In [14], the authors examine the optimal decisions on delivery lead-time and prices in centralized and decentralized supply chains incorporating supplier encroachment. In [19], relevant analytical models are summarized, and a detailed review on strengths and weaknesses of different channel models is given. In [1], a quantity competition model is given. The authors have found that the supplier encroachment can raise the supplier revenue when decreasing the wholesale price. Theoretically, channel coordination should alleviate the channel conflict and yield more profit to partners [3, 26]. However, there is very little research on how to coordinate a dual-channel supply chain. In [9], the authors consider a manufacturer’s pricing strategies in a dual-channel supply chain. They have found that a manufacturer’s contract with a wholesale price and a direct channel price can coordinate the supply channel. In [5], the authors present a discussion on the impact of channel structures and channel coordination on supplier, reseller, and the entire dual-channel supply chain. In [15], a pricing and production decision model is developed in a centralized and decentralized dual-channel supply chain and demand disruption, based on the Stackelberg game theory. In [21], an all-unit quantity-discount mechanism is designed to coordinate the supply chain with asymmetric information on the manufacturer’s unit production cost from the third party’s perspective. In [17], the authors investigate the supplier encroachment, assuming that the reseller has private information about the market size.
They have found that due to supplier encroachment the reseller tends to provide a misleading signal by making a downward quantity order. However, to the best of our knowledge, little attention has been paid to the research on adopting revenue sharing contracts with supplier encroachment. In this paper, we propose a revenue sharing contract to coordinate the dual-channel supply chain under symmetric as well as asymmetric cost information cases.

With regard to contracts with various coordination mechanisms, several studies have been over the past few years [3]. According to [5], a revenue sharing contract is beneficial to manufacturers, resellers and other participants within a supply chain. In [4], the authors study the revenue-sharing contract in a two-echelon distribution channel with competing resellers. They have found that market demand is both reselling price sensitive and stochastic, and only a revenue sharing contract can coordinate the channel. In [20], the authors study the channel performance of supply chains under consignment contracts with revenue sharing. They have found that both the overall channel performance and the performance of individual firms depend critically on demand price elasticity and on the resellers share of channel cost. This indicates that a decentralized supply chain cannot be perfectly coordinated. In [13], a reverse revenue sharing contract is developed. Along with a fixed franchise fee, this contract can coordinate a multi-channel decentralized supply chain. In [25], the authors investigate a revenue-sharing contract for coordinating a supply chain comprising one manufacturer and two competing resellers. They have found that the provision of revenue sharing in the contract can achieve better performance, comparing to a wholesale price-only contract. In [24], the authors investigate emission leakage and contract reshuffling in a load-based program as well as generation emission attribute certificates. They have found that emission leakage and contract reshuffling exhibit a downward trend when the load is reduced and the generation in the unregulated area is increased.

However, the above literature only addresses the issue of pricing and coordination in a dual-channel supply chain under symmetric information. In practice, it may be difficult or impossible for both firms to have the same information about the production cost in the planning period, especially for products with short life-cycle [9]. In reality, the firms always have some private information, such as raw material cost, and labor cost. Asymmetric cost information is very common in the supply chain and hence this should have considerable attention [12]. However, there is little literature studying the dual-channel supply chain under asymmetric information. In [18], the authors investigate the information sharing of value-adding reseller in a hi-tech supply chain based on Stackelberg game. They consider the optimal contract design problem for a hi-tech supply chain when the manufacturer has incomplete information about the resellers adding value. In [23], the authors have found that the multi-channel manufacturer always benefits from an information sharing strategy when both the multi-channel manufacturer and the reseller have private information about consumer demand. In [7], an optimal wholesale contract design problem is developed and the impact of information asymmetry on wholesale contract and profits is investigated.

There are several differences between our model and those publications mentioned above. (i) It is assumed in those papers that the decision information between the supplier and reseller is fully available. (ii) In the existing literature, only a single channel under asymmetric cost information is considered, while we employ a utility function for a representative consumer in a dual-channel supply chain. Then
we discuss the pricing and coordination based on this consumers utility function. (iii) In the existing literature, the focus is on the coordination problem among the supply chain partners. By contrast, we aim to investigate the effect of asymmetric information on optimal policies and analyzing the value of information.

3. Model framework. We consider a dual-channel supply chain, which is composed of a manufacturer and a reseller. The manufacturer may sell the products to the reseller, or end customers directly through on-line stores, catalog sales and factory outlets. For simplicity, the indirect channel is referred to as Channel 1, and the direct channel is referred to as Channel 2. We assume that there is only one type of product for sale. The manufacturer sells the products to the reseller at a wholesale price $w$. The reseller sells the products to end customers at a reselling price $p_1$. The manufacturer sells the products to end customers directly at a direct channel price $p_2$. We use $D_1$ to represent demand in the indirect channel and $D_2$ in the direct channel. Let $c_m$ be the unit cost that the manufacturer charges in direct channel and let $c_r$ be the unit cost that the reseller chargers in indirect channel. We consider the full information case where the manufacturer knows exactly $c_r$ and the asymmetric information case where the manufacturer only knows a prior probability distribution of the resellers cost. The prior probability distribution is denoted by $F(c_r)$ with continuous density $f(c_r)$ defined on $[c_r, \overline{c_r}]$, where $0 \leq c_r \leq \overline{c_r} \leq \infty$.

3.1. Demand functions. To obtain the demand functions in different channels with supplier encroachment, we adopt the elegant framework established in [5] and [16]. A similar utility function for a representative consumer is used as given below:

$$U = \sum_{i=1,2} (A_i D_i - \frac{D_i^2}{2}) - \theta D_1 D_2 - \sum_{i=1,2} p_i D_i, \quad (1)$$

where $A_i$ denotes the market scale of channel $i$, and $\theta (0 \leq \theta \leq 1)$ denotes the channel substitutability. As channel substitutability decreases, the two channels become more monopolistic [5]. $\theta = 0$ and $\theta = 1$ represent, respectively, the channel is purely monopolistic and substitutable. The channels are demand interdependent (unless $\theta = 0$). $A_1$ and $A_2$ are for different market segments. The aggregate demand decreases in $\theta$. Maximizing Eq. (1) yields the demand for channel $i$ as follows:

$$D_i = \frac{A_i - \theta A_{3-i} - p_i + \theta p_{3-i}}{1 - \theta^2}, \quad i = 1, 2. \quad (2)$$

The total demand is:

$$D = \frac{A_1 + A_2 - (p_1 + p_2)}{1 + \theta}. \quad (3)$$

3.2. Profit functions. We investigate a revenue sharing contract (RSC), in which the reseller shares $\phi$ percentage of its revenue with the manufacturer. Suppose that the decentralized dual-channel supply chain adopts the revenue sharing contract $(w, \phi)$, where $w$ represents the wholesale price charged by supplier, and $\phi$ is the percentage of retailers revenue shared with the manufacturer. Then the profit functions of the reseller and the manufacturer can be, respectively, expressed as:

$$\Pi_r = D_1[(1 - \phi)p_1 - w - c_r], \quad (4)$$
$$\Pi_m = D_1(\phi p_1 + w) + D_2(p_2 - c_m), \quad (5)$$

The supply chain total profit function is:

$$\Pi = D_1(p_1 - c_r) + D_2(p_2 - c_m). \quad (6)$$
Obviously, channel prices must exceed the marginal costs \( p_1 \geq c_r \geq 0 \) and \( p_2 \geq c_m \geq 0 \), and channel demands must be nonnegative \( A_1 \geq p_1 \geq c_r \) and \( A_2 \geq p_2 \geq c_m \).

3.3. The manufacturer-reseller game. The manufacturer and the reseller make decisions independently, aiming to maximize their individual profits. The manufacturer acts as the role of Stackelberg game leader and the reseller acts as the role of Stackelberg game follower. The decision process is assumed to follow the following sequence: the manufacturer plays by declaring the revenue sharing contract \((w, \phi)\) and the direct channel price \( p_2 \). Then, the reseller reacts to that policy by determining reselling price \( p_1 \). We solve the Stackelberg game problem by a backward induction.

The reseller’s decision problem is formulated as follows:

\[
\max_{p_1} \Pi_r
\]

The optimal solution \( p_1^* \) can be expressed as a function of the wholesale price \( w \) and the direct price \( p_2 \). The manufacturers response function can be written as follows:

\[
\max_{p_2, w} E\{\Pi_m\}
\]

Note that resellers cost is regarded as a random variable in the manufacturer’s formulation in the asymmetric information setting. However, there is no variant in its formulation when the reseller has full information. We will adopt a backward induction to obtain the solutions to this Stackelberg type leader-follower game problem. We will investigate the optimal policies under full information case followed by the asymmetric information case. Then, we will make a comparison between them.

4. Optimal contract under complete information.

4.1. Centralized decisions. We consider the pricing and production quantity decisions in a centralized dual-channel supply chain, i.e. the manufacturer and the reseller are vertically integrated. Assume that there exists a central decision-maker who seeks to maximize the total profit of the supply chain. The central decision-maker determines the reselling price \( p_1 \) and the direct sale price \( p_2 \) simultaneously. We obtain the optimal prices from the first-order condition about the total profit under a centralized decision case. By substituting the optimal prices into demand function and profit function, we obtain the optimal reselling price \( p_1^C \) and optimal direct price \( p_2^C \) as follows

\[
p_1^C = \frac{1}{2}(A_1 + c_r),
\]

\[
p_2^C = \frac{1}{2}(A_2 + c_m),
\]

and the optimal profit of the dual-channel supply chain is given by

\[
\Pi^C = \frac{A_1^2 + A_2^2 + 2\theta A_2 c_r + c_r^2 - 2(A_2 + \theta c_r)c_m + c_m^2 - 2A_1[\theta(A - 2 - c_m) + c_r]}{4(1 - \theta^2)}.
\]

The optimal production quantities are given by

\[
D_1^C = \frac{A_1 - \theta A_2 - c_r + \theta c_m}{2(1 - \theta^2)},
\]
\[ D^C = \frac{A_2 - \theta A_1 - c_m + \theta c_r}{2(1 - \theta^2)}, \quad (13) \]
\[ D^C = \frac{A_1 + A_2 - c_m - c_r}{2(1 + \theta)}. \quad (14) \]

The demand of each channel must be nonnegative, and the channel substitutability \( \theta \) must satisfy
\[ 0 \leq \theta \leq \min\left\{ \frac{A - 1 - c_r}{A_2 - c_m}, \frac{A_2 - c_m - c_r}{A_1 - c_r} \right\}. \]

The manufacturer’s profit and resellers profit are given by
\[ \Pi^C_m = \left( A_2 - c_m \right) \left( A_2 - c_m - \theta A_1 + \theta c_r \right) + \left[ 2w + \phi(A_1 + c_r) \right] \left( A_1 - \theta A_2 - c_r + \theta c_m \right) \]
\[ 4(1 - \theta^2) \quad (15) \]
\[ \Pi^C_r = \left( 1 - \phi \right) A_1 - 2w - (1 + \phi)c_r \left( A_1 - \theta A_2 - c_r + \theta c_m \right) \]
\[ 4(1 - \theta^2). \quad (16) \]

4.2. Decentralized decisions. In this section, we consider a revenue sharing contract to coordinate a decentralized dual-channel supply chain. To be specific, the manufacturer as the Stackelberg game leader decides the revenue sharing contract and direct channel price, then the reseller as the follower decides the reselling price. We investigate the Stackelberg game by a backward induction and derive the reseller’s optimal decision in Proposition 1.

**Proposition 1.** Under decentralized decision case, the resellers optimal responsive pricing strategy is given by
\[ p^R_1 = \frac{w - (\phi - 1)A_1 + \theta(\phi - 1)A_2 + c_r + (1 - \phi)\theta p_2}{2(1 - \phi)}. \quad (17) \]
And the manufacturers optimal pricing policy is given by
\[ p^R_2 = \frac{1}{2}(A_2 + c_m), \quad (18) \]
\[ w^R = \frac{2(\phi - 1)^2A_1 - 2c_r - \theta\phi(\phi - 1)(A_2 - c_m)}{2(2 - \phi)}. \quad (19) \]

**Proof.** Given the wholesale price and direct channel price, we obtain the reseller's responsive pricing strategy from the first-order condition about the reseller’s profit function. After that, we consider the manufacturer’s optimal pricing policy. As the manufacturer plays a role as the Stackelberg leader, knowing that the reseller’s optimal responsive pricing policy will be given by \( p^R_1 \). Substituting \( p^R_1 \) into the manufacturer’s profit function defined in Eq. (5), the manufacturers optimal policy in Eq. (18) and (19) is obtained in Proposition 1.

Comparing the direct channel prices between the centralized supply chain in Eq. (10) and the decentralized supply chain in Eq. (18), we can see that the two direct channel prices are equal, i.e. \( p^R_2 = p^C_2 \). This implies that the manufacturer’s optimal direct price in the decentralized decision is the same with that in the centralized decision. Let \( w^R \) denote the wholesale price specified in a revenue sharing contract \((w^R, \phi^R)\) If the contract \((w^R, \phi^R)\) can induce the reseller to order \( D^C_1 \) as in Eq. (12), the manufacturer should be able to influence the reseller to set the self-interested reselling price \( p^R_1 \) in Eq. (17) to \( p^C_1 \) in Eq. (9). Thus, the reseller will order \( D^C_1 \) and the order quantity in the direct channel is \( D^C_2 \) given in Eq. (13). If \( p^C_2 \) is given by Eq. (11) and the revenue sharing contract is denoted as \((w^R, \phi^R)\), as
seen in Proposition 4 the manufacturer can adopt the revenue sharing contract \((w^R, \phi^R)\). Also, the manufacturer can induce the reseller to order \(D_1^C\) and set the indirect channel price at \(p_1^C\). Meanwhile, the revenue sharing contract \((w^R, \phi^R)\) can coordinate the dual channels supply chain.

**Proposition 2.** The revenue sharing contracts can coordinate the dual channels supply chain, as follows

\[
w^R = \frac{\theta(1 - \phi^R)(A_2 - c_m)}{2} - \phi^R c_r, \\
\]

and

\[
0 < \phi^R < \frac{\theta(A_2 - c_m)}{\theta(A_2 - c_m) + 2c_r},
\]

*Proof.* From Proposition 1, we know the optimal price strategy must satisfy the following equations

\[
w - (\phi - 1)A_1 + \theta(\phi - 1)A_2 + c_r + (1 - \phi)p_2^R = \frac{A_1 + c_r}{2},
\]

and

\[
p_2^R = \frac{1}{2}(A_2 + c_m).
\]

Solving the equations, we have

\[
w^R = \frac{\theta(1 - \phi^R)(A_2 - c_m)}{2} - \phi^R c_r.
\]

This completes the proof.

Since the wholesale price must be nonnegative, we obtain the range of revenue share. From Eq. (20), it is clear that the wholesale price increases with the channel substitutability \(\theta\) and the direct channel market segments \(A_2\). However, it decreases with reseller’s cost, which is a surprising finding. This outcome may be explained as follows: due to the competition of channels, the wholesale price is higher if the channels’ competition becomes fiercer or the products become more substitutable.

**Corollary 1.** The demands for the dual-channel supply chain under decentralized decision are given by:

\[
D_1^R = D_1^C = \frac{A_1 - \theta A_2 - c_r + \theta c_m}{2(1 - \theta^2)},
\]

\[
D_2^R = D_2^C = \frac{A_2 - \theta A_1 - c_m + \theta c_r}{2(1 - \theta^2)},
\]

\[
D^R = D^C = \frac{A_1 + A_2 - c_m - c_r}{2(1 + \theta)}.
\]

*Proof.* By substituting optimal prices into demand function, the above equations hold.

Under the full information case, when reseller’s cost increases, the demand of the indirect channel and the total demand decrease, and direct channel demand increase. When the reseller’s cost is high, the indirect channel becomes less attractive to the end customers. Consequently, more customers would choose to buy the product from the direct channel. Accordingly, the manufacturer’s profit is:

\[
\Pi_m^R = D_1(\phi p_1 + w) + D_2(p_2 - c_m) = \frac{\phi[A_1 - c_r - \theta(A_2 - c_m)]^2 + (1 - \theta^2)(A_2 - c_m)^2}{4(1 - \theta^2)}.
\]

(21)
The reseller’s profit is
\[
\Pi^R_r = D_1[(1 - \phi)p_1 - w - c_r] = \frac{(1 - \phi)(A_1 - \theta A_2 - c_r + \theta c_m)^2}{4(1 - \theta^2)}.
\] (22)

The supply chain total profit is:
\[
\Pi^R = [A_1 - c_r - \theta(A_2 - c_m)]^2 + \frac{(A_2 - c_m)^2}{4}.
\] (23)

From Eq. (21) and Eq. (22), we can see that the manufacturer’s profit and reseller’s profit will decrease in accordance with reseller’s cost.

5. Optimal contract under asymmetric information. The reseller can have the true cost information in indirect channels. On the other hand, the manufacturer only knows the prior probability distribution of the cost information. A reseller is usually reluctant to reveal its private information, or wishes to protect its advantage by hiding the cost information [18]. In this section, we assume that the manufacturer does not know the exact value of \( c_r \), but has information on its prior probability distribution. Furthermore, we assume that \( c_r \) is uniformly distributed in the interval \([c_r, \bar{c}_r]\). The expected value is
\[
e_A = \int_{c_r}^{\bar{c}_r} c_r f(c_r) dc_r = \frac{c_r + \bar{c}_r}{2}.
\]

Let \( B = \bar{c}_r - c_r \), which is the range of the uncertain cost that the manufacturer estimates. To compare the optimum policies between the full and the asymmetric information cases, we further assume that the market scale of the direct channel \( A_2 \) is large enough, so that
\[
c_r < \frac{(1 - \phi)(3 - \phi)[A_1 - \theta(A_2 - c_m)] + e_A}{2(1 - \phi)^2} \quad \text{and} \quad e_A > A_1 - \theta(A_2 - c_m).
\]

Note that the reseller’s optimal response function is still given by Eq. (17) in Proposition 2. The manufacturer then maximizes the expected profit
\[
\max_{p_2, w} E\{\Pi_m\} = E\{D_1(\phi p_1 + w) + D_2(p_2 - c_m)\}
\]
\[
= \int_{c_r}^{\bar{c}_r} [D_1(\phi p_1 + w) + D_2(p_2 - c_m)] f(c_r) dc_r.
\] (24)

We obtain the optimal policies for the partners in asymmetric information setting.

**Proposition 3.** The reseller’s optimal responsive reselling price is given by \( p_1^R \). Then the manufacturer’s optimal pricing policies in the asymmetric information case are given by
\[
\begin{cases}
p_2^A = \frac{1}{2}(A_2 + c_m), \\
w^A = \frac{2e_A - 2(1 + \phi)^2 A_1 + \theta(1 + \phi) \phi (A_2 - c_m)}{2(-2 + \phi)}.
\end{cases}
\] (25)

**Proof.** Given the reseller’s optimal responsive reselling price, we obtain Eq. (25) from the first-order derivatives of manufacturer’s profit Eq. (24) about direct price and wholesale price, respectively.

Substitute the manufacturer’s optimal policies into reseller’s reaction functions in Eq. (16). Then, the reseller’s optimal policy and the partners’ profits are obtained respectively as given in Corollary 2 and Corollary 3 below.
Corollary 2. The reseller’s optimal pricing policy is given by
\[
P_1^A = \frac{3(A_1 + c_r) - 2\phi A_1 - \theta(1 - \phi)(A_2 - c_m)}{2(2 - \phi)} - \frac{e_A + (1 - 2\phi)c_r}{2(2 - \phi)(1 - \phi)}. \tag{26}
\]

Corollary 3. The demands for the dual-channel supply chain under asymmetric information case are given by:
\[
D_1^A = \frac{e_A - c_r + (1 - \phi)[(A_1 - c_r) - \theta(A_2 - c_m)]}{2(1 - \theta^2)(2 - \phi)(1 - \phi)}, \tag{27}
\]
\[
D_2^A = \frac{\theta(e_A - c_r) + (1 - \phi)[\theta(A_1 - c_r) + (\theta^2(1 - \phi) - 2 + \phi)(A_2 - c_m)]}{2(1 - \theta^2)(2 - \phi)(\phi - 1)}, \tag{28}
\]
\[
D^A = \frac{e_A - c_r + (1 - \phi)[(A_1 - c_r) - (\frac{1}{2} - \theta(-1 + \phi) + \phi)(A_2 - c_m)]}{2(1 + \theta)(2 - \phi)(1 - \phi)}. \tag{29}
\]

Proof. The above equations hold by substituting Eq. (25) and (26) into demand function Eq. (2) and (3). Since Eq. (27) must be nonnegative, it follows that
\[
c_r < \frac{e_A + (1 - \phi)[A_1 - \theta(A_2 - c_m)]}{2 - \phi}.
\]

Suppose it holds that
\[
c_r < \frac{(1 - \phi)(3 - \phi)[A_1 - \theta(A_2 - c_m)] + e_A}{(2 - \phi)^2} \quad \text{and} \quad e_A > A_1 - \theta(A_2 - c_m).
\]

Then
\[
c_r < \frac{e_A + (1 - \phi)[A_1 - \theta(A_2 - c_m)]}{2 - \phi}.
\]

Corollary 4. The profits of the manufacturer and reseller under the asymmetric information case are
\[
\Pi_m^A = \frac{3(1 - \phi)^2[(A_1 - \theta A_2 - c_m)^2 + (2 + \theta^2\phi - \phi - 2\theta^2)(A_2 - c_m)^2]}{12(2 - \phi)(1 - \phi)^2(1 - \theta^2)}
\]
\[
+ \frac{3(1 - \phi)^2[-2e_A(A_1 - \theta A_2 + \theta c_m) + e_A^2] + \frac{1}{4}(-2 + \phi)\phi B^2}{12(2 - \phi)(1 - \phi)^2(1 - \theta^2)}. \tag{30}
\]
\[
\Pi_r^A = \frac{(e_A - c_r + (1 - \phi)((A_1 - c_r) - \theta(A_2 - c_m)))^2}{4(1 - \theta^2)(2 - \phi)^2(1 - \phi)}. \tag{31}
\]

The total profit of the entire dual-channel supply chain is given by
\[
\Pi^A = (2 - \phi)\frac{3(1 - \phi)^2[(A_1 - \theta A_2 - c_m)^2 + (2 + \theta^2\phi - \phi - 2\theta^2)(A_2 - c_m)^2]}{12(2 - \phi)^2(1 - \phi)^2(1 - \theta^2)}
\]
\[
+ \frac{3(1 - \phi)^2[-2e_A(A_1 - \theta A_2 + \theta c_m) + e_A^2] + \frac{1}{4}(-2 + \phi)\phi B^2}{12(2 - \phi)^2(1 - \phi)^2(1 - \theta^2)}
\]
\[
+ \frac{3(1 - \phi)[e_A - c_r + (1 - \phi)[(A_1 - c_r) - \theta(A_2 - c_m)]^2]}{12(1 - \theta^2)(2 - \phi)^2(1 - \phi)^2}. \tag{32}
\]

Proof. The above equation hold by substituting optimal prices into partners’ profit functions.
We know that the direct sale price in Eq. (25) does not change with reseller’s cost information. On the other hand, the reselling price in Eq. (26) and the wholesale price in Eq. (25) decrease with the reseller’s cost. Comparing Eq. (21) with Eq. (30), we can see that the manufacturer incurs profit loss when the reseller’s cost is asymmetric information. Comparing Eq. (22) and Eq. (31), we can see that the reseller can benefit from the asymmetric information.

6. Implications for information management. In this section, we analyze the effect of asymmetric information on profits of the partners. We compare the optimal profits of partners and the dual-channel supply chain under two cases: (i) information is shared; and (ii) information is not shared. We derive the value of information from the manufacturer’s point of view.

**Proposition 4.** The manufacturer sets the same direct channel price both cases, i.e., $p_C^2 = p_R^2 = p_A^2$, and the direct channel price is independent of reseller’s cost. The indirect channel price and wholesale price both increase if the reseller’s cost is moved from asymmetric information case to the full information case, i.e., $w_A^R < w_R^A, p_A^1 < p_R^1 = p_C^1$.

*Proof.* Suppose that $c_r < \frac{(1 - \phi)(3 - \phi)[A_1 - \theta(A_2 - c_m)] + e_A}{(2 - \phi)^2}$ and $e_A > A_1 - \theta(A_2 - c_m)$.

Then

$$e_A - c_r > (1 - \phi)^2[(A_1 - c_r) - \theta(A_2 - c_m)].$$

Thus,

$$\Delta w = w_R^R - w_A^R = \frac{(1 - \phi)^2[(A_1 - c_r) - \theta(A_2 - c_m)] - (e_A - c_r)}{(\phi - 2)} > 0.$$ 

Similarly, we obtain $p_A^1 < p_R^1 = p_C^1$. This completes the proof.

**Proposition 5.** The indirect channel will experience a decreased demand when moving from the asymmetric information case to the full information case, i.e., $D_A^1 > D_R^1 > D_C^1$. The direct channel demand will increase, i.e., $D_A^2 < D_R^2 < D_C^2$. The total demand of the dual-channel will decrease, i.e., $D_A > D_R > D_C$.

*Proof.* Since

$$c_r < \frac{(1 - \phi)(3 - \phi)[A_1 - \theta(A_2 - c_m)] + e_A}{(2 - \phi)^2} \text{ and } e_A > A_1 - \theta(A_2 - c_m),$$

we have

$$\Delta D_1 = \frac{(1 - \phi)^2[(A_1 - c_r) - \theta(A_2 - c_m)] - (e_A - c_r)}{2(1 - \theta^2)(1 - \phi)(2 - \phi)} < 0,$$

$$\Delta D_2 = \frac{\theta[(1 - \phi)^2[(A_1 - c_r) - \theta(A_2 - c_m)] - (e_A - c_r)]}{2(1 - \theta^2)(1 - \phi)(\phi - 2)} > 0,$$

$$\Delta D = \frac{(1 - \phi)^2[(A_1 - c_r) - \theta(A_2 - c_m)] - (e_A - c_r)}{2(1 + \theta)(1 - \phi)(2 - \phi)} < 0.$$ 

This completes the proof.
From Propositions 4 and 5, we see that the information asymmetry leads to lower wholesale price and reselling price, and higher reselling demand and total demand but lower direct channel demand. This is because that when the reseller possesses its private cost information, the reseller has more bargaining power. In other words, the reseller can force the manufacturer, under asymmetric case, to decrease the wholesale price through a revenue sharing contract \((w_A, \phi_A)\). The manufacturer charges a lower wholesale price in the asymmetric information case, while the reseller enjoys a lower purchasing cost included in the wholesale price \(w_A\). Thus, the reseller sells the product to end consumers with a lower reselling price \(p_1\), which makes buying from indirect channel more attractive to the end customers under the asymmetric information case. Therefore, more customers choose to buy the products from the indirect channel. Moreover, the end customers enjoy the lower reselling price and bring a larger total end market demand under the asymmetric information case. Therefore, the demand of direct channel would decrease, because some consumers resort to the indirect channel to buy the product. This leads to a lower demand in the direct channel.

Obviously, moving from the asymmetric to the full information cases, direct channel price will not change, but the direct channel demand increases and the reseller demand and the total demand decrease. Nevertheless, the end customers enjoy larger utility, meaning that the market scale of direct channel \(A_2\) is large enough compared to other parameters. Thus the dual-channel supply chain benefits from sharing more cost information of resellers. We define the information value as the absolute difference between the profits of partners and investigate the value of the asymmetric cost information from the manufacturer’s point of view. We have Proposition 6.

**Proposition 6.** The manufacturer’s profit would increase from the information sharing. The amount of profit increase \(\Delta \Pi_m\) is given by

\[
\Delta \Pi_m = \Pi_R^m - \Pi_m^A = \frac{\phi[A - 1 - c_r - \theta(A_2 - c_m)]^2 + (1 - \theta^2)(A - 2 - c_m)^2}{4(1 - \theta^2)} - \frac{3(1 - \phi)^2[(A_1 - \theta A_2 - c_m)]^2 + (2 + \theta^2 \phi - \phi - 2 \theta^2)(A_2 - c_m)^2}{12(2 - \phi)(1 - \phi)^2(1 - \theta^2)} - \frac{3(1 - \phi)^2[2c_A(A_1 - \theta A_2 + \theta c_m) + c_A^2]_{A_2}^1(-2 + \phi)\phi B^2}{12(2 - \phi)(1 - \phi)^2(1 - \theta^2)} > 0.
\]

**Proof.** The above inequality holds by comparing the manufacturer’s profit Eq. (21) and Eq. (30). \(\Box\)

Proposition 6 quantifies the value of information from the manufacturer’s point of view. It is interesting to see that \(\Delta \Pi_m\) would be the maximum amount the manufacturer would be willing to spend for information. From Proposition 6, we can see that \(\frac{d \Delta \Pi_m}{dB} > 0\), meaning that \(\Delta \Pi_m\) increases at the reseller’s cost range \(B\), although the manufacturer’s profit \(\Pi_R^m\) is independent of \(B\). The less certain about the reseller’s cost information, the higher the value of information for the manufacturer. An important insight obtained here is that the manufacturer should increase the accuracy of the estimated reseller’s cost, i.e. decreasing \(B\) by using information technology and an incentive mechanism to collect the reseller’s cost information.
The reseller will incur profit loss if its cost information is shared with the manufacturer. What is the threshold level that the reseller would be willing to share its cost information? We investigate the value of the asymmetric cost information from the reseller’s point of view. We have Proposition 7.

**Proposition 7.** The reseller’s profit would be lower if the reseller shares its cost information with the manufacturer and the following conditions are satisfied.

\[
c_r < \frac{(1 - \phi)(3 - \phi)(A_1 - \theta(A_2 - c_m)) + e_A}{(2 - \phi)^2} \quad \text{and} \quad e_A > A_1 - \theta(A_2 - c_m).
\]

On the other hand, suppose that the reseller shares its cost information with the manufacturer and that

\[
\frac{(1 - \phi)(3 - \phi)(A_1 - \theta(A_2 - c_m)) + e_A}{(2 - \phi)^2} < c_r < \frac{e_A - (1 - \phi)^2[A_1 - \theta(A_2 - c_m)]}{(2 - \phi)\phi}.
\]

Then, the reseller’s profit will be higher than when information is not shared.

**Proof.** The reseller’s profit difference between the asymmetric and the full information cases is given as follows:

\[
\Delta \pi_r = \Pi^R_r - \Pi^A_r
\]

\[
= \frac{(1 - \phi)(A_1 - \theta A_2 - c_r + \theta c_m)^2}{4(1 - \theta^2)} - \frac{(e_A - c_r + (1 - \phi)((A_1 - c_r) - \theta(A_2 - c_m)))^2}{4(1 - \theta^2)(2 - \phi)^2(1 - \phi)}
\]

\[
= \frac{(1 - \phi)^2((A_1 - c_r) - \theta(A_2 - c_m)) - (e_A - c_r)}{4(1 - \theta^2)(2 - \phi)^2(1 - \phi)}
\]

\[
\times [(1 - \phi)(3 - \phi)((A_1 - c_r) - \theta(A_2 - c_m)) + (e_A - c_m)].
\]

The equation \(\Delta \pi_r = 0\) has two roots given by

\[
c_r1 = \frac{e_A - (1 - \phi)^2[A_1 - \theta(A_2 - c_m)]}{(2 - \phi)\phi} \quad \text{and} \quad c_r2 = \frac{(1 - \phi)(3 - \phi)[A_1 - \theta(A_2 - c_m)] + e_A}{(2 - \phi)^2}.
\]

This completes the proof. \(\square\)

Note that the market scale of the direct channel \(A_2\) is large enough compared to other parameters so that \(e_A > A_1 - \theta(A_2 - c_m)\), which leads to \(c_r1 > c_r2\). Thus

\[
(1 - \phi)^2 ((A_1 - c_r) - \theta(A_2 - c_m)) - (e_A - c_r) < 0 \quad \text{when} \quad c_r < c_r1
\]

and

\[
(1 - \phi)(3 - \phi)((A_1 - c_r) - \theta(A_2 - c_m)) + (e_A - c_r) > 0 \quad \text{when} \quad c_r < c_r2
\]

Therefore, the reseller’s profit would decrease moving from the asymmetric to the full information cases, i.e., \(\Delta \pi_r < 0\) when the information is shared and the conditions are satisfied.

\[
c_r < \frac{(1 - \phi)(3 - \phi)[A_1 - \theta(A_2 - c_m)] + e_A}{(2 - \phi)^2} \quad \text{and} \quad e_A > A_1 - \theta(A_2 - c_m).
\]

We have the following proposition to demonstrate how the profit of each partner changes.
Proposition 8. Suppose that a dual-channel supply chain moves from the asymmetry to the full information cases and that the conditions are satisfied.

\[ c_r < \frac{(1 - \phi)(3 - \phi)[A_1 - \theta(A - 2 - c_m)] + e_A}{(2 - \phi)^2} \quad \text{and} \quad e_A > A_1 - \theta(A_2 - c_m). \]

Then, it holds that the manufacturer’s profit will increase, i.e.,

(i) the manufacturer’s profit will increase, i.e., \( \Pi^m_\text{A} < \Pi^m_\text{R} \),

(ii) the resellers profit will decrease, i.e., \( \Pi^r_\text{A} > \Pi^r_\text{R} \),

(iii) the dual-channel supply chain profit will increase, i.e., \( \Pi^\text{A} < \Pi^\text{R} \).

Proof. Obviously, part (ii) holds from Proposition 7. Part (iii) is valid by comparing the profits of the dual-channel supply chain. From part (ii) and part (iii), part (i) follows readily. This completes the proof.

From Proposition 8, we can see that the reseller’s profit decreases, even though the profit of the supply chain increases. The asymmetric information leads to inefficiency to the manufacturer and the dual-channel supply chain. In other words, the manufacturer and the supply chain will always gain more profits at the cost of the reseller if the reseller shares its cost information. Cost information is more asymmetry, and the reseller would benefit more. Moreover, the increase in the manufacturer’s profit is more than the loss of the reseller’s profit under information sharing. Therefore, the manufacturer should encourage information sharing and must offer compensation to the reseller. Proposition 10 illustrates that the dual-channel supply chain can achieve the coordination under asymmetric information if the manufacturer is willing to offer a lump-sum side payment to reseller. The side payment the manufacturer offered should not be less than \( \Pi^A_\text{r} - \Pi^R_\text{r} \).

7. Numerical experiment. In this section, we will carry out numerical examples to verify the analytical findings. Let \( A_1 = 1100, A_2 = 1000, c_m = 20 \). The resellers cost \( c_r = 160 \) under full information case and \( c_r \in (100, 440) \) under the asymmetric information case. We obtain \( e_A = 270 \) and \( B = 340 \). Since the demand of each channel must be nonnegative, the channel substitutability should satisfy

\[ 0 < \theta < \min\left\{ \frac{A_1 - c_r}{A_2 - c_m}, \frac{A_2 - c_m}{A_1 - c_r} \right\}. \]

We further assume that \( \theta = 0.85 \). The revenue share \( \phi^R \) satisfies

\[ 0 < \phi^R < \frac{\theta(A_2 - c_m)}{\theta(A_2 - c_m) + 2c_r}, \]

where the wholesale price should be nonnegative, and we let \( \phi = 0.4 \). From the above analysis, we derive the optimal policies in Table 1.

| Parameters | \( p_1 \) | \( p_2 \) | \( w \) | \( L_1 \) | \( D_2 \) | \( D \) | \( \pi^m_\text{A} \) | \( \pi^r_\text{A} \) | \( \pi^\text{A} \) |
|---|---|---|---|---|---|---|---|---|---|
| Full Information | 630 | 510 | 185.9 | 192.793 | 246.126 | 518.919 | 244226 | 6188 | 250414 |
| Asymmetric Information | 592.771 | 510 | 141.225 | 326.952 | 212.091 | 539.043 | 230462 | 17799 | 248261 |

Table 1. The optimum policies under full and asymmetric information cases

From Table 1, we can see that the reselling price and the wholesale price in asymmetric information case are lower than those in full information case. On the other hand, the direct channel sale prices do not change, leading to a higher demand.
in the indirect channel and a lower demand in the direct channel. The manufacturer incurs a loss while the reseller benefits from its asymmetric cost information. The profits of the manufacturer and the whole supply chain always increase, if the reseller’s cost information is shared ($\Delta \pi_m = 13764, \Delta \pi = 2153$). The reseller is willing to share its cost information if the manufacturer can compensate reseller’s profit loss. In other words, the reseller would share its cost information if the manufacturer offers a lump-sum side payment more than to reseller. The partners and the dual-channel supply chain would benefit from sharing information. Therefore, in a dual-channel supply chain, obtaining cost information by advanced information technology can improve the profits of the manufacturer and the entire supply chain.

We plot the prices and demand expressions as functions of the channel substitutability under asymmetric information case as shown in Figures. 1 and 2, respectively. From Figure 1, we can see that the direct channel prices do not change and are independent of the channel substitutability $\theta$, while the wholesale and indirect channel prices increase and decrease with respectively. We observe that indirect channel price is higher than the wholesale price and the direct channel price. The difference between the indirect and direct channel prices is the price advantage of the direct channel. The higher the channel substitutable, the weaker the price advantage of the direct channel. Also, higher channel substitutability will force the reseller to reduce the reselling price, which will, however, cause the demand of indirect channel to increase ultimately. It is shown in Figure 2.

![Figure 1. Variation of prices with $\theta$ under asymmetric information case](image)

From Figure 2, we can find that the demand will decrease with $\theta$, while the demand of the indirect channel will increase with $\theta$. Thus the demand of the direct channel must decrease with $\theta$. The insight here is that the manufacturer should decrease $\theta$. As the channel substitutability decreases, the two channels become more monopolistic. The manufacturer would gain more profit from maintaining the price advantage of the direct channel by using operational means like convenient shopping and advertising.

We plot the profit difference of the manufacturer that is expressed as a function of $B$ under the asymmetric information case as shown in Figure 3. We can see that the profit differences of the manufacturer increase with the reseller’s cost range $B$. This means that the less certain about the reseller’s cost information, the higher value of
information for the manufacturer. An important managerial insight obtained here is that the manufacturer should decrease $B$ by using information technology and some incentive mechanisms to collect the reseller’s cost information.

8. **Conclusions.** This paper proposes pricing decision and coordination models in a dual-channel supply chain under full and asymmetric information cases. Firstly, we build an optimal pricing decision model based on the Stackelberg game theory and propose a revenue sharing contract to coordinate the supply chain with full information. Then, we discuss the optimal decision with asymmetric cost information and compare the optimal policies. Moreover, we analyze the value of the reseller’s cost information. Our study has found that the direct prices do not change and are independent of reseller’s cost, while the wholesale price and indirect channel price increases and decreases respectively with more information. Information asymmetry is beneficial to the reseller, but results in inefficiency to the manufacturer and the whole supply chain. The manufacturer will have higher profits by sharing the reseller’s cost information. The reseller is willing to share its cost information, on
condition that the lump-sum side payment offered by the manufacturer can compensate the reseller’s profit loss due to sharing information.

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