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Drug supply chain coordination and contract analysis considering member profit margin and channel power under volumed-based procurement in China

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A B S T R A C T

Volume-Based Procurement has been implemented as a key reform policy in China's pharmaceutical distribution since 2018, resulting in a sharp decline in the profitability of the pharmaceutical supply chain. This paper develops cost and profit models for Decentralized Decision-Making (DD) and Centralized Decision-Making (CD) in a three-tier supply chain comprising one manufacturer, one distributor, and one hospital. Then, under member profit margin, profit allocation based on the impact of channel power, and the increased profit of each member, a coordination contract is designed that includes the range of coordination factors for the distribution fee rate paid by the manufacturer to the distributor and the subsidies provided by the manufacturer to the hospital. Additionally, the boundary of pharmaceutical pricing under both decisions is investigated, and the findings are finally validated through numerical computation. Some results are found: Under CD, the system's overall profit increases. Before profit coordination under CD, the logistics costs for the hospital and manufacturer increase, while the distributor's logistics costs decrease compared with DD, resulting in a concentration of increased profit in the distributor. After coordination, the manufacturer's costs are lower than under DD Furthermore, the pharmaceutical price boundary under CD is lower than that under DD.

1. Introduction

1.1 The problem

In China, by the end of 2024, ten batches of pharmaceutical procurement have been implemented through the Volume-Based Procurement (VBP) mechanism (N.C.P.P.O, 2024). The VBP has been currently normalized and institutionalized in China (G.O.S.C, 2021), which has significantly led to a reduction in pharmaceutical prices, resulting in a substantial decrease in profit, and even supply disruptions (Ke et al., 2024). At this time, studying supply chain coordination under the VBP is beneficial for cost reduction and efficiency improvement and holds practical significance for the members of the pharmaceutical supply chain. Under the VBP, the hospitals' agent (Medical Insurance Bureau) negotiates with a pharmaceutical manufacturer, or multiple pharmaceutical manufacturers compete to generate supply contracts. The pharmaceutical manufacturer produces the pharmaceuticals and is responsible for shipping to the distributor. The distributor then distributes the pharmaceuticals to the hospital. The VBP policy requires the hospital to sell pharmaceuticals at the manufacturer's supply price, without any markup or profit.

When faced with minimal profit, profit target constraints become particularly important for the members' decisions. In supply chain coordination, previous research primarily focuses on maximizing profit and minimizing costs, while there has been no pharmaceutical SC research on coordinating under profit target constraints. The supply chain under VBP presents some new characteristics: The pharmaceutical manufacturer directly reaches purchasing agreements with the hospital, ensuring that the supply of a fixed quantity of pharmaceuticals at a fixed price meets their profit targets. The pharmaceutical distributor charges distribution fees from manufacturers that are not lower than its profit target, and they are only responsible for inventory transfer and distribution without markup. The hospital does not generate a profit from the sale of the pharmaceuticals. In

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Decentralized Decision-Making (DD), the channel power of members is different. The hospital is the first decision maker, aiming to minimize its own inventory and procurement costs. The manufacturers serve as the second decision-makers, focusing on maximizing their profits, while distributors accept decisions passively. Each member aims for their own optimal goals, but the overall cost and profit of the supply chain may not be optimal. If Centralized Decision-Making (CD) is achieved through the coordination contract, the overall cost and profit will change. Supply chain coordination brings benefits (Cachon & Lariviere, 2005; Whang, 1995), a fact well known. When CD generates increased profit, members leverage their channel power to bargain over the increased profit. There are numerous cases illustrating the impact of channel power of members on profit competition, such as Wal-Mart, McDonald's, and P&G leveraging their market advantages to influence power dynamics within supply chain relationships (Munson & Rosenblatt, 2001; Zhang et al., 2022). Therefore, studying different decisions and coordination under the special constraints of supply chain systems with the VBP policy has significant practical value.

1.2 The contribution and structure of the paper

The paper initially examines the optimization of the three-tier supply chain for the VBP policy in China, considering the dual constraints of member profit margins and channel power. The contributions of this paper are summarized as follows. First, we conduct a comparative analysis of DD and CD regarding the VBP in China, finding that the overall profit of the supply chain is improved and logistics costs are reduced under CD. Second, member profit margin constraints are considered in two decision analyses, and the impact of member power is taken into account when allocating increased profit. The profit margin constraint in coordination analysis features as follows: When allocating the increased profit from CD, it is important not only to ensure that the total profit of the members exceeds the previous profit but also to meet the profit margin requirements. This avoids the contradiction where the ratio of cost changes to profit is not synchronized during CD, while also considering the positive impact of members' rights on increased profit. This differs from other literature and is more aligned with real-world situations. Third, this paper analyzes the pharmaceutical price boundary under the member profit margin constraint in DD, and the price boundary in CD is studied, which satisfies the three constraints: increasing member profit, exceeding the minimum profit margin, and power-positive effects on the allocation of increased profit. Additionally, the value ranges of the two coordination factors, the distribution fee rate between the manufacturer and distributor, and the subsidy from the manufacturer to the hospital, are calculated.

1.3 Literature review

There is a considerable amount of literature on supply chain coordination. Our issue involves coordinating replenishment decision factors and freight economic factors, which fall within the scope of the Joint Economic Lot-Size Model (JELP). Additionally, it analyzes the allocation of increased profit on CD under profit constraints and the influence of channel power. Therefore, a literature review will be conducted from these three aspects.

Our research model is based on a single vendor-buyer JELP and incorporates the role of a distributor. The study of JELP started early. Regarding a single-vendor-buyer JELP, Goyal (1977) proposed a solution assuming that the supplier's production capacity is unlimited and that the supplier adopts a batch shipment policy when delivering to the buyer. Monahan (1984) incorporated quantity discount into the single vendor-buyer JELP problem and analyzed the optimal batch decision from the perspectives of both parties, the coordinating decision, and discount pricing, under the assumption that the production quantity for a single batch is dispatched at once and that capacity is unlimited. Banerjee (1986) introduced the concept of JELP under Monnahan’s assumptions, making batch decisions from the perspective of the entire supply chain rather than solely focusing on the optimal decision of one party. Additionally, buyer inventory cost is incorporated, allowing the buyer to be generalized rather than being limited to a supplier with no production capacity. Goyal (1988); Joglekar (1988) extended Monnahan's model by relaxing the production cycle to N times the delivery cycle with limited capacity, and by aiming to maximize the overall profit of the supply chain, comparing it with the optimal DD. The above delivery batches occur after the supply or production batches are completed. Lee (2005) extended the raw material ordering decision to consider the sellers in a two-tier supply chain. Wang and Lee (2013) studied a two-tier supply chain system consisting of a vendor and a buyer, which includes a capacitated warehouse. The research focuses on coordinating optimal production and delivery strategies between the members, with the coordination factors being the maximum inventory levels of both parties and the delivery cycle. This study extends the total cost to include the inventory cost of the members. Lei et al. (2006) analyzed the two-tier system with a carrier, comparing the costs and profits of DD versus CD under the price decision. Our supply chain structure shares similarities with the study of Lei et al. (2006); however, the carrier's responsibilities and associated costs differ. Lei et al. (2006) based their analysis on the carrier being responsible for transportation costs without considering inventory holding costs. Chen et al. (2019) investigated the pricing and ordering decisions in a supply chain composed of a dominant retailer, a manufacturer, and a third-party logistics (3PL) provider. By introducing the logistics service level as an additional variable and applying game theory, the study deduced the equilibrium pricing and ordering decisions of the members. Jiang et al. (2014) studied the issue of cost-sharing in a two-tier system with third-party logistics (3PL), comparing decentralized cost-sharing with centralized cost-sharing mechanisms. The above research focuses on a two-tier supply chain with a single seller-buyer JELP. Next, we will review the relevant JELP literature on three-tier supply chains, with one member at each tier. Khouja (2003) analyzed three coordination mechanisms under the condition of delivering completed production in batch mode: the equal cycle time mechanism, the optimal basic cycle time mechanism, and the integer multipliers mechanism. Ben-Daya and Al-Nassar (2008) changed the condition to production-on-delivery and achieved lower costs than Khouja (2003) under the integer multiple delivery cycle policy. Ben-Daya et al. (2013) integrated the two-echelon supply chain concept proposed by Lee (2005) into the model developed by Ben-Daya and Al-Nassar (2008) for a three-tier supply chain, addressing the supply chain consisting of a single supplier, a single manufacturer, and multiple retailers in a JELP context.

The research on the two-tier JELP has been deepened and expanded. This study enhances the pharmaceutical supply chain by introducing a distributor to the existing single seller-buyer two-tier supply chain. Thus, the supply chain is now a three-tier model, which falls under the basic three-tier model from previous studies but encompasses a wider range of costs, including order setup costs, inventory costs, and transportation costs between members. On the other hand, this study not only examines the coordination of procurement batches between the two upstream tiers and the two downstream tiers but also incorporates the coordination of delivery fee rates between manufacturers and distributors, which differs from previous literature.

The article also analyzes the impact of member profit constraints and member power on profit-sharing contracts. Thus, it is necessary to review the coordination contracts under these two constraint conditions. In terms of profit-constrained coordination contracts, Krishnan and Soni (1997) investigated the game of the two-echelon supply chain under the retailer's channel power while ensuring the retailer's profit. Deng and Yano (2016) studied contract design in buyer-supplier supply chains under random demand, where each party maximizes its expected profit but is subject to opportunity constraints in order to achieve its respective profit target. They derived the optimal contract form, encompassing both stochastic and deterministic payments, for all types of contracts. Hu et al. (2018) investigated the supplier's optimal decision under the retailer's profit margin constraint and the effect of that constraint on supply chain coordination, focusing on wholesale-price contracts and revenue-sharing contracts within this supply chain structure. Matsui (2019) investigated the timing problem of profit margin set by retailers in a two-tier supply chain under conditions of uncertain information among supply chain members, with the retailer exercising channel power. Choi et al. (2022) examined the coordination advantages of commonly used contracts under different retailer profit targets.

In terms of member channel power, member power influence arises due to the asymmetry in member relationships (Simon, 1953). Gaski (1984) reviewed the research on sales channel power and conflict, defining channel member power. There are many examples demonstrating the impact of member channel power on profit competition, such as Walmart, McDonald's, and Procter & Gamble leveraging their market advantages to exert power within supply chain relationships (Munson & Rosenblatt, 2001; Zhang et al., 2022). Regarding zero-markup for pharmaceuticals and VBP, previous research has mainly focused on the themes of pharmaceutical economics and healthcare services. In contrast, studies related to inventory ordering, particularly those concerning zero-markup for pharmaceuticals and VBP, are quite limited. Liu et al. (2022) proposed a joint replenishment and delivery model for a two-tier supply chain, aiming to minimize total costs that encompass warehouse-related and demander-related costs, upstream transportation costs, and downstream distribution costs.

Research on the two-tier JELP has deepened. This study enhances the pharmaceutical supply chain by introducing a distributor to the traditional single-vendor-buyer chain. The supply chain is the traditional producer-distributor-retailer chain. However, the cost considerations of supply chain members are broader, encompassing order setup costs, inventory costs at all levels, and transportation costs among members. On the other hand, this study not only analyzes the joint procurement batches between the two upstream tiers and the two downstream tiers but also incorporates the coordination of the delivery rate factor between the manufacturer and distributor, which differs from previous literature. Furthermore, under the VBP policy, pharmaceuticals do not incur a markup when passing through distributors, and neither the distributor nor the hospital generates a profit from pharmaceutical sales, which is a unique characteristic of this supply chain. Lastly, based on the differences in channel power among members, this article analyzes the impact of each member's profit margin objectives and channel power on the allocation of increased profit under centralized procurement policies. It calculates the range of values for the coordination factors. This is different from research on the coordination of economic factors among supply chains.

2. Model Formulation

The three-tier supply chain studied is composed of a manufacturer, a distributor, and a hospital. In DD, the pharmaceutical manufacturer sets supply prices to meet its profit rate targets and reach supply agreements with the hospital. As the most powerful of the SC, the hospital makes decisions first and sets the purchasing cycle according to its target of the lowest logistics cost. The manufacturer makes two decisions: the delivery cycle and the delivery fee rate paid to the distributor. The distributor finally makes the purchasing and distribution decision passively, but the profit rate target should not be lower than its target. Otherwise, the distributor and the manufacturer cannot reach a distribution agreement. The symbols are shown in Table 1. During system operation, the shipment cycle of the manufacturer must be equal to the purchasing cycle of the distributor, and the delivery cycle of the distributor must be equal to the purchasing cycle of the hospital; otherwise, the system cannot be formed.

The assumptions are as follows.

(i.) The manufacturer signs agreements with the hospital regarding the supply price and quantities of pharmaceuticals, and the hospital sells the pharmaceuticals at the supply prices, adhering to the VBP policy. Exogenous supply market factors influence pharmaceutical price.

(ii.) The manufacturer aims to maximize profit with a profit margin exceeding β. Likewise, the distributor's goal is to achieve a profit margin greater than α. The hospital, however, operates without pharmaceutical markups, focusing on minimizing logistics costs.

(iii.) The hospital has a constant demand rate. The manufacturer produces uniformly at the hospital's rate of demand, ensuring that there will be no stock shortages.

(iv.) The manufacturer and distributor maintain unlimited inventory capacity and are responsible for associated inventory costs. The manufacturer bears its shipping cost to the distributor, and its shipping capacity is limitless.

(v.) The distributor delivers pharmaceuticals to the hospital at the purchase price, without markup, and bills the manufacturer for delivery services based on the pharmaceutical's value multiplied by a fixed freight rate. Delivery capacity is unlimited.

(vi.) In practice, the pharmaceutical manufacturer and distributor typically have specialized, large-scale pharmaceutical distribution centers, whereas the hospital only possesses smaller pharmaceutical storage facilities. Due to the economies of scale in storage, the unit inventory holding cost of the hospital is greater than that of the manufacturer and distributor, i.e., $h_h > h_d$ and $h_h > h_m$. The difference between h_m and h_d is not significant. The purchase setup cost of the hospital is less than that of the distributor due to differences in business complexity (Hill, 1999), i.e., $k_h < k_d$. Since the shipment between the manufacturer and the distributor is generally long-distance, the fixed shipping cost for the manufacturer is substantially higher than the purchase setup cost of the distributor, the fixed delivery cost and the purchase setup cost for the hospital, i.e., $c_1 >> k_d$ $c_1 >> c_3$ and $c_1 >> k_h$.

Table 1
Symbols for the formulation.

member	symbols	implication	note
manufacturer (*m*)	T	shipment cycle	decision variable
	d	production rate	parameter
	h_m	unit inventory holding cost	parameter
	c	unit production cost	parameter
	c_1	fixed shipping cost	parameter
	c_2	unit varied shipping cost	parameter
	p	pharmaceutical price	exogenous parameter
distributor (*d*)	T	procurement cycle	decision variable
	τ	delivery cycle	decision variable
	λ	delivery fee rate	coordination variables
	k_d	procurement setup cost	parameter
	c_3	fixed delivery cost	parameter
	c_4	unit varied delivery cost	parameter
	h_d	unit inventory holding cost	parameter
hospital (*h*)	τ	procurement cycle	decision variable
	k_h	procurement setup cost	parameter
	h_h	unit inventory holding cost	parameter
system	C	system cost per unit time	variable
	Π	system profit per unit time	variable

Note: The superscript * on the symbols denotes the optimal value of the symbol. Symbols with suffix D indicate the DD state; with suffix *C*, they represent the state before the allocation of increased profits after CD; and with suffix *CC*, they denote the state after the allocation of the increased profits following CD.

The hospital's total costs include procurement setup costs, inventory holding costs, and payments for pharmaceuticals. The costs per unit time are formulated as Eq. (1), and the logistics cost is formulated as Eq. (2). Since the hospital does not sell pharmaceuticals at a markup, the loss is formulated as Eq. (3).

$$C_h = \frac{k_h}{\tau} + \frac{dh_h\tau}{2} + dp \tag{1}$$

$$C_{hl} = \frac{k_h}{\tau} + \frac{dh_h\tau}{2} \tag{2}$$

$$\Pi_h = -\frac{k_h}{\tau} - \frac{dh_h\tau}{2} = -C_{hl} \tag{3}$$

The total cost of the manufacturer includes shipping costs, inventory holding costs, production costs, and delivery fees paid to the distributor. The manufacturer's cost per unit time is formulated as Eq. (4). Then, the manufacturer's logistics cost per unit time is formulated as Eq. (5), and the manufacturer's profit per unit time is formulated as Eq. (6).

$$C_m = \frac{c_1}{T} + \frac{dh_m T}{2} + dc_2 + dc + dp\lambda \tag{4}$$

$$C_{ml} = \frac{c_1}{T} + \frac{dh_m T}{2} + dc_2 \tag{5}$$

$$\prod_m = dp - \frac{c_1}{T} - \frac{dh_m T}{2} - dc_2 - dc - dp\lambda = dp - C_{ml} - dc - dp\lambda \tag{6}$$

The total cost of the distributor includes purchase setup costs, inventory holding costs, and delivery costs. The cost per unit time is formulated as Eq. (7), then the logistics cost per unit time is formulated as $C_{dl} = C_d$, and the profit per unit time is formulated as Eq. (8).

$$C_d = \frac{k_d}{T} + \frac{c_3}{\tau} + \frac{dh_d(T-\tau)}{2} + dc_4 \tag{7}$$

$$\prod_d = dp\lambda - \frac{k_d}{T} - \frac{c_3}{\tau} - \frac{dh_d(T-\tau)}{2} - dc_4 = dp\lambda - C_{dl} \tag{8}$$

The overall cost of the supply chain is formulated as Eq. (9), and the logistics cost is formulated as Eq. (10), where $dc + dp$ is the production cost. The overall profit of the supply chain is formulated as Eq. (11).

$$C = \frac{c_1 + k_d}{T} + \frac{dT(h_m + h_d)}{2} + \frac{c_3 + k_h}{\tau} + \frac{d\tau(h_h - h_d)}{2} + d(c + c_2 + c_4 + p\lambda + p) \tag{9}$$

$$C_l = \frac{c_1 + k_d}{T} + \frac{dT(h_m + h_d)}{2} + \frac{c_3 + k_h}{\tau} + \frac{d\tau(h_h - h_d)}{2} + d(c_2 + c_4) \tag{10}$$

$$\prod = d(p - c - c_2 - c_4) - \frac{c_1 + k_d}{T} - \frac{dT(h_m + h_d)}{2} - \frac{c_3 + k_h}{\tau} - \frac{d\tau(h_h - h_d)}{2} \tag{11}$$

3. Costs and profit analysis under different decisions

3.1 Cost and profit analysis under DD

In DD, based on the strength of the channel power, members independently make their optimal decisions under profit margin constraints. With the pharmaceutical price and quantity fixed in the VBP contract, the optimal decision only considers costs. The hospital acts as the buyer, holding the greatest power without a markup. The hospital first determines its optimal procurement cycle based on its logistics cost. Then, the manufacturer, as the second strongest party, makes optimal low-cost decisions that involve maintaining a profit margin above β. Finally, the distributor passively accepts the optimal decision made by the hospital and the manufacturer and undertakes the delivery task, provided that the distribution fee does not fall below the profit margin α. In the decision-making process, there is an implicit constraint: the manufacturer's shipping cycle T must be greater than the distributor's delivery cycle τ for the distributor to have sufficient inventory.

Since the hospital first makes decisions, its cost function Eq. (1) is only related to the procurement cycle τ, and is continuous and smooth. Due to the power, the hospital can make independent decisions on the purchasing cycle τ. Therefore, when the optimal purchasing cycle $\tau_D^* = \sqrt{\frac{2k_h}{dh_h}}$, the hospital's minimum cost is $C_{Dh}^* = \sqrt{2dk_h h_h} + dp$. Since the hospital has no markup, its maximum acceptable loss is $\prod_{Dh}^* = -\sqrt{2dk_h h_h}$.

The manufacturer makes decisions regarding components $\frac{c_1}{T} + \frac{dh_m T}{2}$ and $dp\lambda$ based on its minimum cost C_m . The manufacturer determines the optimal shipping cycle for the component cost $\frac{c_1}{T} + \frac{dh_m T}{2}$, while the delivery cost $dp\lambda$ must satisfy the distributor's delivery fee constraints. The manufacturer makes an optimal decision $T_D^* = \sqrt{\frac{2c_1}{dh_m}}$. The delivery fee $dv\lambda$ paid to the distributor must ensure the distributor's profit $\prod_{Dd} \geq \alpha C_{Dd}$. The distributor passively accepts the manufacturer's optimal delivery cycle T_D^*. Due to *Assumption* (vi.) $c_1 > k_h$ and $h_m < h_h$, the optimal delivery cycle $\sqrt{\frac{2c_1}{dh_m}}$ for the manufacturer is greater than the optimal procurement cycle $\sqrt{\frac{2k_h}{dh_h}}$ of the hospital, and therefore, the optimal shipping cycle of the manufacturer is $T_D^* = \sqrt{\frac{2c_1}{dh_m}}$. At this point, the distributor's optimal costs are $C_{Dd}^* = \frac{k_d}{T_D^*} + \frac{c_3}{\tau_D^*} + \frac{dh_d(T_D^* - \tau_D^*)}{2} + dc_4$, and the profit must satisfy $\prod_{Dd} \geq \alpha C_{Dd}$. Since the distributor's profit is determined by the distribution charge paid by the manufacturer, the manufacturer's minimum delivery fee rate λ satisfies the distributor's minimum profit constraint $\prod_{Dd}^* = \alpha C_{Dd}^*$. Therefore, the optimal delivery fee rate $\lambda_D^* = \frac{(1+\alpha)C_{Dd}^*}{dp}$, the minimum cost of the manufacturer $C_{Dm}^* = \frac{c_1}{T_D^*} + \frac{dh_m T_D^*}{2} + dc + dc_2 + dp\lambda_D^*$, and the maximum profit of the manufacturer are calculated as Eq. (12). The minimum overall cost of the supply chain is calculated as Eq. (13). The maximum profit of the supply chain is calculated as Eq. (14).

$$\prod_{Dm}^* = dp - C_{Dm}^* = dp - C_{Dml}^* - dc - dp\lambda_D^* = dp - dc - dc_2 - dc_4(1+\alpha) - \frac{c_1 + (1+\alpha)k_d}{T_D^*} - \frac{\left(dh_m + (1+\alpha)dh_d\right)T_D^*}{2} - \frac{c_3(1+\alpha)}{\tau_D^*} + (1+\alpha)\tau_D^* \tag{12}$$

$$C_D^* = C_{Dm}^* + C_{Dd}^* + C_{Dh}^* = \frac{c_1 + k_d}{T_D^*} + \frac{dT_D^*(h_m + h_d)}{2} + \frac{\left(c_3 + k_h\right)}{\tau_D^*} + \frac{d\tau_D^*(h_h - h_d)}{2} + d(c + c_2 + c_4 + p\lambda_D^* + p) \tag{13}$$

$$\prod_D^* = 2dp + dp\lambda_D^* - C_{Dm}^* - C_{Dd}^* - C_{Dh}^* = d(p - c - c_2 - c_4) - \frac{c_1 + k_d}{T_D^*} - \frac{dT_D^*(h_m + h_d)}{2} - \frac{c_3 + k_h}{\tau_D^*} - \frac{d\tau_D^*(h_h - h_d)}{2} \tag{14}$$

The pharmaceutical price, p, is affected by market competition and is exogenous; however, there is a minimum frontier for pharmaceutical prices, subject to the profit constraints of supply chain members. The hospital's losses are unrelated to the price, as the hospital has no markup; only the manufacturer's and distributor's profits are related to the price. Therefore, price p must satisfy two conditions that the manufacturer's profit is greater than β times its cost, i.e., $\prod_{DF}^* \geq \beta C_{DF}^*$, and the distributor's profit is greater than α times its cost, i.e., $\prod_{Dd}^* \geq \alpha C_{Dd}^*$, under the optimal decision T^*, τ^*, and λ^*. Since the decentralized optimal decision is already solved with $\prod_{Dd}^* > \alpha C_{Dd}^*$ as a constraint, the optimal decision already satisfies the distributor's profit constraint. Therefore, the pharmaceutical price p only satisfies $\prod_{Dm}^* \geq \beta C_{Dm}$, i.e.,
$dp - \frac{c_1}{T_D^*} - \frac{dh_m T_D^*}{2} - dc - dc_2 - dp\lambda_D^* \geq \beta\left(\frac{c_1}{T_D^*} + \frac{dh_m T_D^*}{2} + dc + dc_2 + dp\lambda_D^*\right)$, $p_D \geq \frac{(1+\beta)\left(C_{Dml}^* + dc\right) + (1+\beta)(1+\alpha)C_{Dd}^*}{d}$, and thus the boundaries of p under decentralized decision-making are obtained, as shown in Eq. (15). From the formulation of p, the p bound is related to the manufacturer's and distributor's profit constraints, and the larger the profit margin, the larger the boundary.

$$p_D^B = \frac{(1+\beta)\left(C_{Dml}^* + dc\right) + (1+\beta)(1+\alpha)C_{Dd}^*}{d} \tag{15}$$

3.2 Cost and profit analysis under CD

Under CD and profit-sharing contracts, the overall cost and profit of the SC will change, which will impact the members.

Proposition 1 The SC profit function under CD has a maximum value. Furthermore, CD is more profitable than DD.
$T_C^* = \sqrt{\frac{2(k_d + c_1)}{d(h_m + h_d)}}$ and $\tau_C^* = \sqrt{\frac{2(c_3 + k_h)}{d(h_h - h_d)}}$ are the optimal CD when the system's profit $\prod_C^*$ is
$d(p_C - c - c_2 - c_4) - \sqrt{2d\left(c_1 + k_d\right)\left(h_m + h_d\right)} - \sqrt{2d\left(c_3 + k_h\right)\left(h_h - h_d\right)}$.

Proof. In the SC profit function Eq. (11), the cost function consists of sub-functions $\frac{c_1+k_d}{T}+\frac{dT(h_m+h_d)}{2}$ and $\frac{c_3+k_h}{\tau}+\frac{d\tau(h_h-h_d)}{2}$. The two sub-functions are functions of the independent decisions T and τ, respectively, and are continuous and smooth. The polynomia $\frac{c_1+k_d}{T}+\frac{dT(h_m+h_d)}{2}\geq\sqrt{2d\left(c_1+k_d\right)\left(h_m+h_d\right)}$. When $T_C^*=\sqrt{\frac{2(k_d+c_1)}{d(h_m+h_d)}}$, the minimum value of the polynomial, derived from the AM-GM inequality, is $\sqrt{2d\left(c_1+k_d\right)\left(h_m+h_d\right)}$ .Similarly, the polynomial $\frac{c_3+k_h}{\tau}+\frac{d\tau(h_h-h_d)}{2}\geq\sqrt{2d\left(c_3+k_h\right)\left(h_h-h_d\right)}$. When $\tau_C^*=\sqrt{\frac{2\left(c_3+k_h\right)}{d\left(h_h-h_d\right)}}$, the minimum value is $\sqrt{2d(c_3+k_h)(h_h-h_d)}$. Therefore, the SC's maximum profit is $d(v-c-c_2-c_4)-\sqrt{2d\left(c_1+k_d\right)\left(h_m+h_d\right)}-\sqrt{2d(c_3+k_h)(h_h-h_d)}$.

In addition, the manufacturer's shipping cycle T (the distributor's purchasing cycle) must be greater than the distributor's delivery cycle τ (the hospital's purchasing cycle). Next, to prove $T_C^*>\tau_C^*$. Comparing T_C^* and τ_C^* is equivalent to comparing $\frac{2(k_d+c_1)}{d(h_m+h_d)}-\frac{2(c_3+k_h)}{d(h_h-h_d)}$ with 0. Given *Assumption* (vi.), $c_1>>c_3$ and $k_d>c_h$, $\frac{2(k_d+c_1)}{d(h_m+h_d)}>\frac{2(c_3+k_h)}{d(h_h-h_d)}$.Therefore, $T_C^*>\tau_C^*$. Then, $T_C^*=\sqrt{\frac{2(k_d+c_1)}{d(h_m+h_d)}}$ and $\tau_C^*=\sqrt{\frac{2(c_3+k_h)}{d(h_h-h_d)}}$ are the optimal decisions under CD. Proof completed.

Proposition 2 Under the optimal CD before increased profit allocation, the hospital's cost C_{Ch}^* and losses $\prod_{Ch}^*$ increase, and the costs for the distributor C_{Cd}^* are lower, leading to increased profit.

Proof. The distributor cost function Eq. (7) consists of sub-polynomial $\frac{k_d}{T}+\frac{dh_dT}{2}$ and $\frac{c_3}{\tau}-\frac{dh_d\tau}{2}+dc_4$. Two polynomials are functions of the independent decisions T and τ, respectively, and are continuous and smooth. The derivative of $\frac{k_d}{T}+\frac{dh_dT}{2}$ is $-\frac{k_d}{T^2}+\frac{dh_d}{2}$. Thus, when the distributor makes its self-optimal decision, $T_s^*=\sqrt{\frac{2k_d}{dh_d}}$. $\frac{k_d}{T}+\frac{dh_dT}{2}$ is optimal. Similarly, the derivative of $\frac{c_3}{\tau}-\frac{dh_d\tau}{2}+dc_4$ is $-\frac{c_3}{\tau^2}-\frac{dh_d}{2}$. Given the convexity of the function and the constraint $T>\tau$, the hospital's self-optimal decision $\tau_S^*=\sqrt{\frac{2k_d}{dh_d}}$. Hence, the self-optimal decision of the distributor and the hospital is $T_S^*=\tau_S^*=\sqrt{\frac{2k_d}{dh_d}}$, optimal DD is $T_D^*=\sqrt{\frac{2c_1}{dh_m}}$, $\tau_D^*=\sqrt{\frac{2k_h}{dh_h}}$, , and optimal CD is $T_C^*=\sqrt{\frac{2(k_d+c_1)}{d(h_m+h_d)}}$ and $\tau_C^*=\sqrt{\frac{2(c_3+k_h)}{d(h_h-h_d)}}$. Compare T_S^*, T_D^*, T_C^* and τ_S^*, τ_C^*, respectively, and analyze the change of the cost function based on the functional properties of corresponding $\frac{k_d}{T}+\frac{dh_dT}{2}$ and $\frac{c_3}{\tau}-\frac{dh_d\tau}{2}+dc_4$. First, compare T_S^*, T^*,, and T_C^*. (i), compare T and T^*. Given Assumption (vi.), $c_1>>k_d$, and the difference between h_m and h_d is not significant, then $T_S^*<T_D^*$ from the two decision expressions. (ii), comparing T_D^* and T_C^* equals comparing $c_1(h_m+h_d)-h_m(k_d+c_1)$ and 0. $c_1(h_m+h_d)-h_m(k_d+c_1)=c_1h_d-k_dh_m$. Because $c_1>>k_S$ and the difference of h_m and h_d is not substantial, $c_1h_d-k_dh_m>0$, $\sqrt{\frac{2c_1}{dh_m}}>\sqrt{\frac{2(k_d+c_1)}{d(h_m+h_d)}}$, then $T_D^*>T_C^*$. (iii), comparing T_S^* and T_C^* equals comparing $k_d(h_m+h_d)-h_d(k_d+c_1)$ and 0. $k_d(h_m+h_d)-h_d(k_d+c_1)=k_dh_m-c_1h_d<0$.. Then $T_S^*<T_C^*$. Hence, $T_S^*<T_C^*<T_D^*$. Due to the convexity of the function $\frac{k_d}{T}+\frac{dh_dT}{2}$, it can be concluded that the value is smaller in CD than in DD. Second, comparing τ_D^* and τ_C^* isequal to the comparison of $k_h(h_h-h_d)-h_h(c_3+k_h)$ and 0. $k_h(h_h-h_d)-h_h(c_3+k_h)=k_hh_d-c_3h_h$. Because Assumption (vi.) $c_1>>k_d$ and $h_h>h_d$, then $k_hh_d-c_3h_h<0$.. Hence, the polynomial $\frac{c_3}{\tau}-\frac{dh_d\tau}{2}+dc_4$ is smaller at τ_D^* than at τ_C^*, i.e.,

$\sqrt{\frac{2k_h}{dh_h}} < \sqrt{\frac{2(c_3+k_h)}{d(h_h-h_d)}}$.. The value of $\frac{c_3}{\tau} - \frac{dh_d\tau}{2} + dc_4$ is smaller in *CD* than in *DD*, so the distributor's cost decreases, and the profit increases in *CD*. Third, the value of $\frac{c_1}{T} + \frac{dh_m T}{2}$, the polynomial in the cost function of the manufacturer, is smaller in *DD* than in *CD*. If profit are not coordinated, i.e., the manufacturer pays the same $dp\lambda$ as in *DD*, the manufacturer's profit becomes lower. Therefore, before the coordination of profit under *CD*, the manufacturer's profit declines and the hospital's cost rises; yet with the supply chain's total profit expanding, the profit consequently flows toward distributors.

In the above proof, it is found that both distributor cost and hospital losses after *CD* are only related to the decision variables *T* or *τ*, and not to the coordination variable *λ*. Therefore, if the delivery factor λ is coordinated, the distributor's cost and the hospital's losses remain unchanged.

4. Analysis of the coordination contract under CD

In CD, the overall profit of the system is higher compared to DD. This demonstrates that effective coordination encourages members to participate actively in centralized planning. Members benefit from a partial increase in profit. The profit coordination process involves two steps. First, the manufacturer and distributor facilitate profit transfer through the delivery fee rate *λ*. This step transfers the profits owed to the manufacturer and hospital from the distributor to the manufacturer. Second, due to the increased losses faced by the hospital under CD, the hospital cannot offset these costs by lowering the supply price, as the VBP policy mandates selling at the supply price. To ensure contractual compliance, the manufacturer maintains the supply price unchanged and subsidizes the hospital with *σ*. After increased profit coordination, the profit of each member still needs to satisfy its profit margin constraint, which is the first condition for members to participate in the supply chain. The second condition for members to make CD is that their profits are higher after coordination than in DD. The members with strong power in the channel will obtain larger additional profits than those with weak power, which is the third condition of the coordination contract. These three conditions are the essential requirements of the CD coordination contract.

Due to the members' power, the manufacturer coordinates the allocation of profit with the distributor first through the delivery fee rate *λ* and then coordinates the subsidy to the hospital. The manufacturer's profit after coordinating profit with the distributor is denoted by $\prod^*_{CCm1}$. The manufacturer's profit after coordinating subsidies to the hospital σ is $\prod^*_{CCm}$, then $\prod^*_{CCm1} = \prod^*_{CCm} + \sigma$.. The hospital's loss before coordinating subsidies is $\prod^*_{Ch}$. The hospital's losses after coordination are $\prod^*_{CCh}$, then $\prod^*_{CCh} = \prod^*_{Ch} + \sigma$..

4.1 Boundary analysis of the pharmaceutical price p

In *CD* and increased profit coordination, the member's profit margin constraints, the increase in the member's profit, and the higher the power, the greater the increased allocation are internal constraints of the supply chain system. The pharmaceutical price *p* is exogenous and represents an external constraint on the overall profit of the supply chain. In VBP, the boundary of pharmaceutical price *p* is the lowest price constraint for the manufacturer's market competition. The boundary of pharmaceutical price *p* is crucial for the manufacturer's market competition.

Proposition 3 There exists a coordination mechanism that enables each member to obtain higher profits under CD than under DD, and simultaneously leads to lower costs of the manufacturer and distributor, i.e., $\Pi^*_{CCm} > \Pi^*_{Dm}$, $C^*_{CCm} < C^*_{Dm}$, $\Pi^*_{CCd} > \Pi^*_{Dc}$, and $C^*_{CCd} > C^*_{Dd}$. Additionally, the distributor's costs remain unchanged after the profit coordination in the CD.

Proof. Because CD in the supply chain generates increased profit, there is necessarily reasonable coordination that allows the profit of each member after coordination to be greater than under DD. After the optimal CD, the hospital's losses become larger. The manufacturer needs to subsidize the hospital σ, and its profit after coordination is greater than the profit in DD. In other words, $\Pi^*_{CCm} > \Pi^*_{Dm}$, i.e., $dp - C^*_{CCm} - \sigma \geq dp - C^*_{Dm}$, then $C^*_{CCm} + \sigma \leq C^*_{Dm}$. Therefore, the manufacturer's cost is lower after CD than in DD, $C^*_{CCm} \leq C^*_{Dm}$. Next, the changes in the distributor's costs and profits will be analyzed. Since the distributor's cost function, Eq. (7), is independent of factors *λ* and *σ*, the distributor's optimal costs remain constant after the optimal CD, regardless **of** the profit coordination. Therefore, under a given CD, coordination factors λ and σ do not affect the distributor's costs. Consequently, even after coordination, the distributor's costs remain lower than the costs under DD, as established in Proposition 2. Proof completed.

Proposition 4 If the pharmaceutical price *p* is greater than the boundary in DD, there exists a coordination factor *λ* and *σ* such that the manufacturer satisfies $\prod^*_{CCm} > \prod^*_{Dm} > \beta C^*_{Dm} > \beta C^*_{CCm}$, the distributor satisfies $\prod^*_{CCd} > \prod^*_{Dd} > \alpha C^*_{Dd} > \alpha C^*_{CCd}$, and the hospital satisfies $\prod^*_{CCh} > \prod^*_{Dh}$. If the pharmaceutical price *p* is in the interval between the value when the manufacturer's profit satisfies $\prod_{CCm}^{*}=\beta C_{CCm}^{*}$, the distributor's profit satisfies $\prod_{CCd}^{*}=\alpha C_{CCd}^{*}$, and the hospital's losses satisfies $\prod_{Ch}^{*}+\sigma-\prod_{Dh}^{*}=\prod_{CCm}^{*}-\prod_{Dm}^{*}$ and the boundary of *p* in *DD*, it still exist the coordination factor λ and σ such that the manufacturer satisfies $\beta C_{Dm}^{*}>\prod_{CCm}^{*}>\beta C_{CCm}^{*}>\prod_{Dm}^{*}$, the distributor satisfies $\prod_{CCd}^{*}>\prod_{Dd}^{*}>\alpha C_{Dd}^{*}>\alpha C_{CCd}^{*}$, and hospital satisfies $\prod_{CCh}^{*}>\prod_{Dh}^{*}$ after the coordination in *CD*.

Proof. If the pharmaceutical price *p* is larger than its boundary in DD, i.e., $p\geq\frac{(1+\beta)\left(C_{Dml}^{*}+dc\right)+(1+\beta)(1+\alpha)C_{Dd}^{*}}{d}$, derived from Section 3.1, the manufacturer's profit satisfies $\prod_{Dm}^{*}>\beta C_{Dm}^{*}$, and the distributor's profit satisfies $\prod_{Dd}^{*}>\alpha C_{Dd}^{*}$. Given Proposition 2 and 3, there exist coordination factors *λ* and *σ* that allow the manufacturer's and distributor's costs to be lower in CD compared to DD, i.e., $C_{Dm}^{*}>C_{CCm}^{*}$, $C_{Dd}^{*}>C_{CCd}^{*}$, while their profit is higher, i.e., $\prod_{CCm}^{*}>\prod_{Dm}^{*}$, $\prod_{CCd}^{*}>\prod_{Dd}^{*}$. Consequently, the manufacturer adheres to the condition $\prod_{CCm}^{*}>\prod_{Dm}^{*}>\beta C_{Dm}^{*}>\beta C_{CCm}^{*}$, the distributor adheres to the condition $\prod_{CCd}^{*}>\prod_{Dd}^{*}>\alpha C_{Dd}^{*}>\alpha C_{CCd}^{*}$, , and the sum of the hospital's loss and the manufacturer's subsidy is less than the loss under the DD, i.e., $\prod_{CCh}^{*}>\prod_{Dh}^{*}$. When the price *p* exceeds the boundary condition of DD, the profits of both the manufacturer and the distributor after coordination surpass those achieved under DD, while overall profits increase. Furthermore, each member also satisfies the cost constraints of the CD model. The hospital benefits from these efficiencies, experiencing lower costs due to the subsidy. This suggests that when *p* is lower than the boundary of the first case, both constraints can still be satisfied. The lower boundary of the pharmaceutical price *p* in CD, to a certain extent, enhances the market competitiveness of the manufacturer.

A further price reduction renders the manufacturer's profit constraints infeasible under DD. However, centralizing decision-making leads to a larger overall system profit, allowing for coordinated solutions that satisfy the manufacturer's profit constraints. Significantly, the minimum *p* needs to meet the following conditions. (i) The manufacturer's profit satisfies $\prod_{CCm}^{*}=\beta C_{CCm}^{*}$ after profit coordination. This condition requires that, after coordination, the manufacturer's profit must satisfy the two constraints $\prod_{CCm}^{*}>\beta C_{CCm}^{*}$ and $\prod_{CCm}^{*}>\prod_{Dm}^{*}$. Since $\beta C_{CCm}^{*}>\prod_{Dm}^{*}$ is inevitable after coordination, proven in Proposion 4, the smallest *p* only satisfies $\prod_{CCm}^{*}=\beta C_{CCm}^{*}$ to fulfill the two constraints above. (ii) The distributor's profit remains the same after coordination, i.e., $\prod_{CCd}^{*}=\prod_{Dd}^{*}=\alpha C_{Dd}^{*}=dv\lambda_{C}^{*}-C_{Cd}^{*}$.. This is because, after CD, the dealer's costs decrease. If, after coordination, the profit is not less than the profit under DD, then the dealer's profit must satisfy both its profit margin constraint and its profit-increasing constraint. (iii) The hospital's increased profit needs to be equal to the manufacturer's increased profit, i.e., $\prod_{Ch}^{*}+\sigma-\prod_{Dh}^{*}=\prod_{CCm}^{*}-\prod_{Dm}^{*}$. The reasons are as follows: Hospital losses must satisfy $\prod_{Ch}^{*}+\sigma>\prod_{Dh}^{*}$, and the hospital's profit increase must be at least equal to the manufacturer's profit increase, due to the hospital's greater channel power. Therefore, the minimum *p* satisfies Eq. (16), then the boundary is calculated as Eq. (17).

$$\begin{cases}\prod_{CCd}^{*}=\alpha C_{Dd}^{*}=dp\lambda-C_{Cd}^{*}\\ \prod_{CCm}^{*}=\beta C_{CCm}^{*}\\ \prod_{Ch}^{*}+\sigma-\prod_{Dh}^{*}=\prod_{CCm}^{*}-\prod_{Dm}^{*}\end{cases} \tag{16}$$

$$p_{C}^{B}=\frac{(1+\beta)\left(C_{CCml}^{*}+dc+\alpha C_{Dd}^{*}+C_{Cd}^{*}\right)+\left(\prod_{Dh}^{*}-\prod_{Ch}^{*}-C_{CCml}^{*}-C_{Cd}^{*}+C_{Dml}^{*}+C_{Dd}^{*}\right)/2}{d} \tag{17}$$

When the pharmaceutical price *p* is between the minimum value and the boundary of the first case, the manufacturer's profit margin under DD constraint is not met, i.e., $\beta C_{Dm}^{*}>\prod_{Dm}^{*}$.. Yet, CD can increase system profits, and the costs for both the manufacturer and distributor decrease after centralization. Therefore, the reasonable coordination still ensures that the manufacturer's profit satisfies $\prod_{CCm}^{*}>\beta C_{CCm}^{*}$, and the distributor's profit satisfies $\prod_{CCd}^{*}>\beta C_{CCd}^{*}$.. Thus, the manufacturer's profit satisfies $\prod_{CCm}^{*}>\prod_{Dm}^{*}>\beta C_{Dm}^{*}>\beta C_{CCm}^{*}$, the distributor's profit satisfies $\prod_{CCd}^{*}>\prod_{Dd}^{*}>\alpha C_{Dd}^{*}>\alpha C_{CCd}^{*}$, and the hospital's loss satisfies $\prod_{CCh}^{*}>\prod_{Dh}^{*}$.. Proof completed.

4.2 Range analysis of coordinated factors λ and σ under the margin constraint

Proposition 4 analyses two different cases for *p*. Now, we analyze the range of the coordination factors. The manufacturer's profit after coordination must be greater than β times the cost in CD, i.e., $\prod_{CCm}^{*}>\beta C_{CCm}^{*}$. At the same time, it is also greater than the profit in DD, i.e, $\prod_{CCm}^{*}>\prod_{Dm}^{*}$. Similarly, the distributor's profit after coordination must be greater than α times the cost in CD, i.e., $\prod_{CCd}^{*}>\alpha C_{CCd}^{*}$.. At the same time, it is also greater than the profit in DD, i.e, $\prod_{CCd}^{*}>\prod_{Dd}^{*}$.. The hospital's losses after coordination are greater than in DD, i.e., $\prod_{Ch}^{*}+\sigma\geq\prod_{Dh}^{*}$.. Therefore, the coordination factor *λ* and hospital subsidy

σ in the two cases in *CD* satisfy the inequalities (Iqs.) in Eq. (18).

$$\begin{cases} \prod_{CCm}^{*}(\lambda,\sigma) \geq \max\left(\prod_{Dm}^{*},\beta C_{CCm}^{*}\right) \\ \prod_{CCd}^{*}(\lambda) \geq \max\left(\prod_{Dd}^{*},\alpha C_{CCd}^{*}\right) \\ \prod_{Ch}^{*}+\sigma \geq \prod_{Dh}^{*} \end{cases} \tag{18}$$

In the first case of *p*, based on Proposition 4, $\prod_{Dm}^{*} > \beta C_{\mathrm{CCm}}^{*}$, , then $\max\left(\prod_{Dm}^{*},\beta C_{CCm}^{*}\right)=\prod_{Dm}^{*}$. $\prod_{Dd}^{*} > \alpha C_{\mathrm{CCd}}^{*}$, , then $\max\left(\prod_{Dd}^{*},\alpha C_{CCd}^{*}\right)=\prod_{Dd}^{*}$. The coordination factors satisfy Eq. (19), where $\prod_{CCm}^{*}=dv-C_{CCml}^{*}-dc-dv\lambda-\sigma$, and $\prod_{CCd}^{*}=dv\lambda-C_{Cd}^{*}$. Next, we perform inequality system calculations. The first inequality plus the third inequality simplifies to $dp\lambda \leq dp\text{-}C_{CCml}^{*}-dc-\prod_{Dm}^{*}-\prod_{Dh}^{*}+\prod_{Ch}^{*}$, and the second inequality simplifies to $\lambda \geq (\prod_{Dd}^{*}+C_{Cd}^{*})/dp$. Thus, the interval of the coordination factor λ is obtained as Formula (Fm.) (20). In addition, simplify inequality $dp-C_{CCml}^{*}-dc-dp\lambda-\sigma \geq \prod_{Dm}^{*}$ to get $\sigma \leq dp-C_{CCml}^{*}-dc-\prod_{Dm}^{*}-dp\lambda$ and simplify inequality $\prod_{Ch}^{*}+\sigma \geq \prod_{Dh}^{*}$ to get $\sigma \geq \prod_{Dh}^{*}-\prod_{Ch}^{*}$. Therefore, the interval of the coordination factor σ is obtained as Eq. (21), and the interval of the coordination factor σ varies depending on the value of λ.

$$\begin{cases} dv-C_{CCml}^{*}-dc-dv\lambda-\sigma \geq \prod_{Dm}^{*} \\ dv\lambda-C_{Cd}^{*} \geq \prod_{Dd}^{*} \\ \prod_{Ch}^{*}+\sigma \geq \prod_{Dh}^{*} \end{cases} \tag{19}$$

$$\lambda \in \left[\frac{\prod_{Dd}^{*}+C_{Cd}^{*}}{dp},\frac{dp-C_{CCml}^{*}-dc-\prod_{Dm}^{*}-\prod_{Dh}^{*}+\prod_{Ch}^{*}}{dp}\right] \tag{20}$$

$$\sigma \in \left[\prod_{Dh}^{*}-\prod_{Ch}^{*},dp-C_{CCml}^{*}-dc-\prod_{Dm}^{*}-dp\lambda\right] \tag{21}$$

In the second case, based on Proposition 4, $\prod_{Dm}^{*} < \beta C_{\mathrm{CCm}}^{*}$, then $\max\left(\prod_{Dm}^{*},\beta C_{\mathrm{CCm}}^{*}\right)=\beta C_{\mathrm{CCm}}^{*}$. $\prod_{Dd}^{*} > \alpha C_{\mathrm{CCd}}^{*}$, then $\max\left(\prod_{Dd}^{*},\alpha C_{CCd}^{*}\right)=\prod_{Dd}^{*}$. The coordination factors satisfy Eq. (22), Next, we perform inequality system calculations. The 1st inequality plus the 3rd inequality simplifies to $\lambda \leq \frac{dp-(1+\beta)\left(C_{CCml}^{*}+dc\right)+\prod_{Ch}^{*}-\prod_{Dh}^{*}}{dp+\beta dp}$, and the second inequality simplifies to $\lambda \geq \left(\prod_{S}^{*}+C_{CS}^{*}\right)/dv$. Thus, the interval of the coordination factor λ is as Eq. (23). In addition, simplify the inequality $dp-C_{CCml}^{*}-dc-dp\lambda-\sigma \geq \beta(C_{CCml}^{*}+dc+dp\lambda)$ to get $\sigma \leq dp-(1+\beta)\left(C_{CCml}^{*}+dc\right)-(1+\beta)dp\lambda$ and simplify the inequality $\prod_{Ch}^{*}+\sigma \geq \prod_{Dh}^{*}$ to get $\sigma \geq \prod_{Dh}^{*}-\prod_{Ch}^{*}$.. Therefore, the interval of the coordination factor σ is obtained as Eq. (24), and the interval of the coordination factor σ varies depending on the value of λ.

$$\begin{cases} dp-C_{CCml}^{*}-dc-dp\lambda-\sigma \geq \beta(C_{CCml}^{*}+dc+dp\lambda) \\ dp\lambda-C_{Cd}^{*} \geq \prod_{Dd}^{*} \\ \prod_{Ch}^{*}+\sigma \geq \prod_{Dh}^{*} \end{cases} \tag{22}$$

$$\lambda \in \left[\frac{\prod_{S}^{*}+C_{CS}^{*}}{dv},\frac{dv-(1+\beta)\left(C_{CCFL}^{*}+dc\right)+\prod_{CH}^{*}\text{-}\prod_{H}^{*}}{dv+\beta dv}\right] \tag{23}$$

$$\sigma \in \left[\prod_{Dh}^{*}-\prod_{Ch}^{*},dp-(1+\beta)\left(C_{CCml}^{*}+dc\right)-(1+\beta)dp\lambda\right] \tag{24}$$

4.3 Impact of power on profit coordination

The range of coordination factors, λ and σ, is designed not only to enable supply chain members to meet their profit margin constraints but also to guarantee that the members benefit from the additional profit generated. In addition, the allocation of increased profit in the supply chain after CD follows that the additional increased profit of those with strong power is larger than that of those with weak power. In the pharmaceutical supply chain, the hospital has the strongest power, the manufacturer is weaker than the hospital, and the distributor is the weakest. It also imposes constraints on the coordination factor λ and the hospital subsidy σ. Therefore, the increased profit of the manufacturer, distributor, and hospital is subject to the following constraints: the manufacturer's profit difference is greater than the distributor's profit difference between CD and DD, and the hospital's profit difference is greater than the manufacturer's profit difference between CD and DD. The above constraints are modeled as Eq. (25), and transformed into Iq. (26). The 1st inequality of Eq. (26) is multiplied by 2 minus -2 to get $dp\lambda < \frac{C_{Dml}^* + 3dp\lambda^* - C_{CCml}^* + 2C_{Cd}^* - 2C_{Dd}^* + \prod_{Ch}^* - \prod_{Dh}^*}{3}$. Thus, the interval of the coordination factor λ is obtained as Eq. (27), and then by transforming the constraints, the interval of the coordination factor σ is obtained as Eq. (28).

$$\begin{cases} \prod_{CCm}^* - \prod_{Dm}^* > \prod_{CCd}^* - \prod_{Dd}^* \\ \prod_{CCh}^* - \prod_{Dh}^* > \prod_{CCm}^* - \prod_{Dm}^* \end{cases} \tag{25}$$

$$\begin{cases} 2dp\lambda + \sigma < C_{Dml}^* + 2dp\lambda^* - C_{CCml}^* + C_{Cd}^* - C_{Dd}^* \\ 2\sigma + dp\lambda > C_{Dml}^* + dp\lambda^* - C_{CCml}^* - \prod_{Ch}^* + \prod_{Dh}^* \end{cases} \tag{26}$$

$$\lambda \in \left[0 \in \frac{C_{Dml}^* + 3dp\lambda^* - C_{CCml}^* + 2C_{Cd}^* - 2C_{Dd}^* + \prod_{Ch}^* - \prod_{Dh}^*}{3dp} \right] \tag{27}$$

$$\sigma \in \left[\frac{C_{Dml}^* + dp\lambda^* - C_{CCml}^* - \prod_{Ch}^* + \prod_{Dh}^* - dp\lambda}{2}, C_{Dml}^* + 2dp\lambda^* - C_{CCml}^* + C_{Cd}^* - C_{Dd}^* - 2dp\lambda \right] \tag{28}$$

Based on sections 4.2 and 4.3, analyze the coordination factor that jointly influences increased profit from the constraints of profit margins and the member power. In the first case, given (23), (24), (27), and (28), the coordination factors, λ and σ, satisfy Eqs. (29). In addition, it is necessary to ensure that σ has a value, and then it is essential to fulfill the intersection of 2nd and 4th inequalities in Eqs. (29), i.e., $dp - C_{CCml}^* - dc - \prod_{Dm}^* - dp\lambda > \left(C_{Dml}^* + dp\lambda^* - C_{CCml}^* - \prod_{Ch}^* + \prod_{Dh}^* - dp\lambda\right)/2$, to obtain Eq. (30). Then, combine Eqs. (29) and Eq. (30) to calculate the boundary of the coordination factors λ and σ, it is formulated as Eqs. (31).

$$\begin{cases} \left(\prod_{Dd}^* + C_{Cd}^*\right)/dp < \lambda < \left(dp - C_{CCml}^* - dc - \prod_{Dm}^* - \prod_{Dh}^* + \prod_{Ch}^*\right)/dp \\ \prod_{Dh}^* - \prod_{Ch}^* < \sigma < dp - C_{CCml}^* - dc - \prod_{Dm}^* - dp\lambda \\ 0 < \lambda < \left(C_{Dml}^* + 3dp\lambda^* - C_{CCml}^* + 2C_{Cd}^* - 2C_{Dd}^* + \prod_{Ch}^* - \prod_{Dh}^*\right)/3dp \\ \left(C_{Dml}^* + dp\lambda^* - C_{CCml}^* - \prod_{Ch}^* + \prod_{Dh}^* - dp\lambda\right)/2 < \sigma < C_{Dml}^* + 2dp\lambda^* - C_{CCml}^* + C_{Cd}^* - C_{Dd}^* - 2dp\lambda \end{cases} \tag{29}$$

$$\lambda < \left(2dp - C_{CCml}^* - 2dc - 2\prod_{Dm}^* - C_{Dml}^* - dp\lambda^* + \prod_{Ch}^* - \prod_{Dh}^*\right)/dp \tag{30}$$

$$\begin{cases} \left(\prod_{Dd}^* + C_{Cd}^*\right)/dp < \lambda < \min\begin{pmatrix} \left(dp - C_{CCml}^* - dc - \prod_{Dm}^* - \prod_{Dh}^* + \prod_{Ch}^*\right)/dp, \\ \left(C_{Dml}^* + 3dp\lambda^* - C_{CCml}^* + 2C_{Cd}^* - 2C_{Dd}^* + \prod_{Ch}^* - \prod_{Dh}^*\right)/3dp, \\ \left(2dp - C_{CCml}^* - 2dc - 2\prod_{Dm}^* - C_{Dml}^* - dp\lambda^* + \prod_{Ch}^* - \prod_{Dh}^*\right)/dp \end{pmatrix} \\ \max\begin{pmatrix} \prod_{Dh}^* - \prod_{Ch}^*, \\ \left(C_{Dml}^* + dp\lambda^* - C_{CCml}^* - \prod_{Ch}^* + \prod_{Dh}^* - dp\lambda\right)/2 \end{pmatrix} < \sigma < \min\begin{pmatrix} dp - C_{CCml}^* - dc - \prod_{Dm}^* - dp\lambda, \\ C_{Dml}^* + 2dp\lambda^* - C_{CCml}^* + C_{Cd}^* - C_{Dd}^* - 2dp\lambda \end{pmatrix} \end{cases} \tag{31}$$

In the second case, given Eq. (23), Eq. (24), Eq. (27), and Eq. (28), the coordination factors, λ and σ, satisfy Eq. (32). In addition, it is necessary to ensure that σ has a value, and then it is necessary to satisfy the intersection of inequalitys 2 and 4, i.e., $dp - (1+\beta)\left(C_{CCml}^* + dc\right) - (1+\beta)dp\lambda > \left(C_{Dml}^* + dp\lambda^* - C_{CCml}^* - \prod_{Ch}^* + \prod_{Dh}^* - dp\lambda\right)/2$, to obtain Eq. (33). Then combine Eqs. (32) and Eqs. (33) to calculate the boundary of the coordination factors λ and σ, it is formulated as Eq. (34).

$$\begin{cases} \left(\prod_{Dd}^* + C_{Cd}^*\right)/dp < \lambda < \left(dp - (1+\beta)\left(C_{CCml}^* + dc\right) + \prod_{Ch}^* - \prod_{Dh}^*\right)/\left(dp + \beta dp\right) \\ \prod_{Dh}^* - \prod_{Ch}^* < \sigma < dp - (1+\beta)\left(C_{CCml}^* + dc\right) - (1+\beta)dp\lambda \\ 0 < \lambda < \left(C_{Dml}^* + 3dp\lambda^* - C_{CCml}^* + 2C_{Cd}^* - 2C_{Dd}^* + \prod_{Ch}^* - \prod_{Dh}^*\right)/3dp \\ \left(C_{Dml}^* + dp\lambda^* - C_{CCml}^* - \prod_{Ch}^* + \prod_{Dh}^* - dp\lambda\right)/2 < \sigma < C_{Dml}^* + 2dp\lambda^* - C_{CCml}^* + C_{Cd}^* - C_{DS}^* - 2dp\lambda \end{cases} \tag{32}$$

$$\lambda < \left(dp - (1+\beta)\left(C_{CCml}^* + dc\right) - \left(C_{Dml}^* + dp\lambda^* - C_{CCml}^* - \prod_{Ch}^* + \prod_{Dh}^*\right)/2\right)/\left(dp/2 + dp\beta\right) \tag{33}$$

$$\begin{cases} \left(\Pi_{Dd}^{*}+C_{Cd}^{*}\right)/dp<\lambda<\min\begin{pmatrix}\left(dp-(1+\beta)\left(C_{CCml}^{*}+dc\right)+\Pi_{Ch}^{*}-\Pi_{Dh}^{*}\right)/(dp+\beta dp),\\ \left(C_{Dml}^{*}+3dp\lambda^{*}-C_{CCml}^{*}+2C_{Cd}^{*}-2C_{Dd}^{*}+\Pi_{Ch}^{*}-\Pi_{Dh}^{*}\right)/3dp,\\ \left(dp-(1+\beta)\left(C_{CCml}^{*}+dc\right)-\left(C_{Dml}^{*}+dp\lambda^{*}-C_{CCml}^{*}-\Pi_{Ch}^{*}+\Pi_{Dh}^{*}\right)/2\right)/(dp/2+dp\beta)\end{pmatrix} \\ \max\begin{pmatrix}\Pi_{Dh}^{*}-\Pi_{Ch}^{*},\\ \left(C_{Dml}^{*}+dp\lambda^{*}-C_{CCml}^{*}-\Pi_{Ch}^{*}+\Pi_{Dh}^{*}-dp\lambda\right)/2\end{pmatrix}<\sigma<\min\begin{pmatrix}dp-(1+\beta)\left(C_{CCml}^{*}+dc\right)-(1+\beta)dp\lambda,\\ C_{Dml}^{*}+2dp\lambda^{*}-C_{CCml}^{*}+C_{Cd}^{*}-C_{Dd}^{*}-2dp\lambda\end{pmatrix}\end{cases} \quad (34)$$

5. Numerical illustration

The parameters in the model are assigned numerical values based on the practical business in VBP, as shown in Table 2.

Table 2
Parameter value

member	denotations	implication	value
manufacturer	d	production rate	1000 units
	h_m	unit-inventory-holding cos	0.1$/（day*unit）
	c	unit production cost	8$/unit
	c_1	fixed shipping cost	500$/time
	c_2	unit varied shipping cost	0.8$/unit
distributor	k_d	procurement setup cost	100$/time
	c_3	fixed delivery cost	200$/time
	c_4	unit varied delivery cost	0.4$/unit
	h_d	unit inventory holding cost	0.1$/（day*unit）
hospital	k_h	procurement setup cost	50$/time
	h_h	unit inventory holding cost	0.2$/（day*unit）

(1) Calculation of exogenous price boundaries

The optimal decision and the distributor's cost under *DD* are calculated, $T_D^* = 3.1623$, $\tau_D^* = 0.7071$, and $C_{Dd}^* = 837.224$. The optimal decisions and the distributor's cost under CD are calculated, T_C^*=2.4495, , $\tau_C^* = 2.2361$, and $C_{Cd}^* = 540.9386$. Given Eq. (15), the function of the pharmaceutical price boundary under DD is $p_D^B = (1+\beta)[26116+837.224(1+\alpha)]/1000$. Given Eq.(17), the pharmaceutical boundary under the VBP is $p_C^B = [9126.6(1+\beta)+540.9386(1+\beta)(1+\alpha)+104.5461]/1000$. . In general, the distribution fee rate of distributors is very low, typically less than 1. Thus, $p_C^B < p_D^B$ is obtained by comparing the expression of p_C^B and p_C^B. Currently, the distributor's profit rate under VBP is relatively fixed, typically ranging from 2% to 5%, while the manufacturer's profit rate is lower than 10%. For some basic pharmaceuticals, the profit rate is very low, taking α=3% and β=5%. Consequently, the boundary of the pharmaceutical price is obtained, p_D^B=10.4775 and p_C^B=10.2725. In the previous analysis, when p is taken at different intervals, the intervals of the contractual coordination factors are different. Next, two cases, $p = 11$ and $p = 10.4$, are taken for separate calculations.

(2) Optimization analysis in CD

Regardless of $p = 11$ or $p = 10.4$, the logistics cost of the supply chain in DD $C_l^* = 2094.9$, and the logistics cost of the supply chain in CD $C_{Cl}^* = 1913.5$, which saves $\Delta C = C_l^* - C_{Cl}^*$=181.4, and the optimization rate reaches 8.66%. It can be seen that CD has a greater optimization effect.

(3) The contract and member state analysis in CD

The values of the variables associated with the members are shown in Table 3.

Table 3
Variable value

	Variable	value	Variable	value	Variable	value
p=11	Π_{Dd}^*	25.1167	Π_{Dm}^*	1021.4	C_{Dm}^*	9978.6
	Π_{Dh}^*	-141.4214	Π_{Ch}^*	-245.9675	C_{Cd}^*	540.9386
p=10.4	Π_{Dd}^*	25.1167	Π_{Dm}^*	421.4315	C_{Dm}^*	9978.6
	Π_{Dh}^*	-141.4214	Π_{Ch}^*	-245.9675	C_{Cd}^*	540.9386

In the first case, when $p=11$, given Table 3 and Eqs. (31), the interval of λ, [0.0515,0.0570], is obtained. Taking the distribution rate factor $\lambda=0.055$, the interval of the producer subsidized hospital σ is [175.7580,208.0252] by Eqs. (31). Taking σ=200, the states of each member after the coordination of CD and DD are obtained, as shown in Table 4.

Table 4
The status of each member after DD and CD (*p*=11)

	member	variable	value	variable	value	variable	value
DD	supply chain	C_D^*	21957	C_{Dl}^*	2094.9	Π_D^*	905.1268
	manufacturer	C_{Dm}^*	9978.6	C_{Dml}^*	1116.2	Π_{Dm}^*	1021.4
	distributor	C_{Dd}^*	837.224	C_{Ddl}^*	837.224	Π_{Dd}^*	25.1168
	hospital	C_{Dh}^*	1114.1	C_{Dhl}^*	141.4214	Π_{Dh}^*	-141.4214
CD	Supply chain	C_{CC}^*	21519	C_{Cl}^*	1913.5	Π_{CC}^*	1086.5
	manufacturer	C_{CCm}^*	9731.6	C_{CCml}^*	1126.6	Π_{CCm}^*	1068.4
	distributor	C_{CCd}^*	540.9386	C_{CCdl}^*	540.9386	Π_{CCd}^*	64.0614
	hospital	C_{CCh}^*	1124.6	C_{CChl}^*	245.9675	Π_{CCh}^*	-45.9675
acquired allocation	Manufacturer obtains 47		Distributor obtains 38.9446		Hospital obtains 95.4539		Total 181.3732

From the analysis of Table 4, when $p=11$ the manufacturer's profit after CD coordination reaches 11% (1068.4/9731.6), and the distributor's profit reaches 12% (64.0614/540.9386), both fully satisfy the profit rate constraints. Furthermore, in terms of additional profit obtained by members, the hospital receives the most, followed by the manufacturer, while the distributor gets the least. The results align with the constraints of profit allocation based on the channel power.

In the second case $p=10.4$, based on Table 3 and the interval formulation of λ, the interval for λ is obtained as [0.0544, 0.0592] by Iqs. (34). By setting the coordination contract allocation fee rate factor $\lambda=0.0591$, the subsidy factor σ for the distributor to the hospital falls within the range of [170.9380, 171.6994]. By setting σ = 171, the status of each member after DD and CD contract coordination is derived, as shown in Table 5.

Table 5
The status of each member after DD and CD (*p*=10.4)

	member	variable	value	variable	value	variable	value
DD	supply chain	C_D^*	21357	C_{Dl}^*	2094.9	Π_D^*	305.1268
	manufacturer	C_{Dm}^*	9978.6	C_{Dml}^*	1116.2	Π_{Dm}^*	421.4315
	distributor	C_{Dd}^*	837.224	C_{Ddl}^*	837.224	Π_{Dd}^*	25.1168
	hospital	C_{Dh}^*	1054.1	C_{Dhl}^*	141.4214	Π_{Dh}^*	-141.4214
CD and	supply chain	C_{CC}^*	20938	C_{Cl}^*	1913.5	Π_{CC}^*	486.4953
	manufacturer	C_{CCm}^*	9741.2	C_{CCml}^*	1126.6	Π_{CCm}^*	487.7614
	distributor	C_{CCd}^*	540.9386	C_{CCdl}^*	540.9386	Π_{CCd}^*	73.7014
	hospital	C_{CCh}^*	1064.6	C_{CChl}^*	245.9675	Π_{CCh}^*	-74.9675
acquired allocation	manufacturer obtains 66.3299		distributor obtains 48.5846		hospital obtains 66.4539		total 181.3684

From the analysis of Table 5, when $p=10.4$, , under DD, the manufacturer's profit reaches 4.22% (421.4315/9978.6), which does not meet the profit constraint. However, after profit coordination in DD, the manufacturer's profit rate is 5.00% (487.7614/9741.2), while the distributor's profit rate reaches 13.62% (73.7014/540.9386); both fully satisfy the profit margin constraints. Furthermore, in terms of additional profit obtained by members, the hospital receives the most, followed by the manufacturer, while the distributor gets the least. The results reflect the impact of the channel power on profit allocation.

5. Conclusion

This article models the operating cost and profit of the three-tier supply chain under the VBP policy in China. It analyzes the changes in the overall and member costs and profits of the supply chain under DD and CD. The article also examines the coordination contracts, investigates the pharmaceutical price boundary under different decision-making, and calculates the ranges of the coordination factors for the delivery fee rate λ and the transfer subsidy σ to the hospital under three constraints: member profit margin constraints, profit enhancement after CD, and the impact of member power on increased profit allocation. Additionally, it is found as follows.

First, CD results in higher overall profit for the supply chain compared to DD, and CD also leads to a reduction in overall logistics costs for the supply chain. Second, in terms of the members, under CD, the logistics costs for the hospital and manufacturer increase, while the logistics costs for the distributor decrease. As a result, before the profit in CD is coordinated, the overall profit of the supply chain is concentrated among the distributor. Third, when coordinating the allocation of the increased profit generated by CD, the profit margin constraints have a limiting effect on the influence of members' power on the increased profit. This leads to the profit margin and power affecting the range of values for two coordination factors: the distribution fee rate paid by the manufacturer to the distributor and the subsidies provided by the manufacturer to the hospital.

It is also found that there is a significant relationship between the coordination factors of the delivery fee rate and subsidies to hospitals. Fourth, under the constraints that members' profit increases, profit margins, and power positively influence profit in CD, the minimum price of pharmaceuticals is lower than that in DD. This is very beneficial for manufacturers in terms of market competition and public welfare.

The object of this study is a three-tier supply chain under the VBP policy, where each tier of the supply chain consists of a single member. The system's network structure is relatively simple, which differs from reality, where each tier may have multiple members. To some extent, this research lays a foundation for optimizing supply chains in complex networks under the VBP policy.

CRediT authorship contribution statement

Jufeng Yang: Conceptualization, Methodology, Software, Validation, Writing-original draft, Visualization, Formal analysis. Sujian Li: Conceptualization, Methodology, Writing-review &editing, Supervision.

Data availability

Data will be made available on request.

References

Banerjee, A. (1986). On "A Quantity Discount Pricing Model to Increase Vendor Profits". *Management Science*, *32*(11), 1513-1517. http://www.jstor.org/stable/2631507

Ben-Daya, M., & Al-Nassar, A. (2008). An integrated inventory production system in a three-layer supply chain. *Production Planning & Control*, *19*(2), 97-104. https://doi.org/10.1080/09537280801895930

Ben-Daya, M., As'ad, R., & Seliaman, M. (2013). An integrated production inventory model with raw material replenishment considerations in a three layer supply chain. *International Journal of Production Economics*, *143*(1), 53-61. https://doi.org/10.1016/j.ijpe.2010.10.024

Cachon, G. P., & Lariviere, M. A. (2005). Supply Chain Coordination with Revenue-Sharing Contracts: Strengths and Limitations. *Management Science*, *51*(1), 30-44. https://doi.org/10.1287/mnsc.1040.0215

Chen, X., Xu, P., Walker, T., Huang, S., & Chen, Y.-W. (2019). Pricing and Ordering Decisions in a Retailer Dominant Channel Involving a Third‐Party Logistics Provider. *Complexity*, *2019*(1). https://doi.org/10.1155/2019/1954016

Choi, T.-M., Wang, Y., & Shen, B. (2022). Selling to Profit-Target-Oriented retailers: Optimal supply chain contracting with bargaining. *International Journal of Production Economics*, *250*. https://doi.org/10.1016/j.ijpe.2022.108617

Deng, S., & Yano, C. A. (2016). Designing Supply Contracts Considering Profit Targets and Risk. *Production and Operations Management*, *25*(7), 1292-1307. https://doi.org/10.1111/poms.12561

G.O.S.C, G. O. o. t. S. C. i. C. (2021). *Guiding Opinions on Promoting the Regular and Institutionalized Implementation of Centralized Volume-Based Drug Procurement*. (2). Retrieved from https://www.gov.cn/zhengce/content/2021-01/28/content_5583305.htm

Gaski, J. F. (1984). The Theory of Power and Conflict in Channels of Distribution. *Journal of Marketing*, *48*(3), 9-29. https://doi.org/10.2307/1251326

Goyal, S. K. (1977). An integrated inventory model for a single supplier-single customer problem. *International Journal of Production Research*, *15*(1), 107-111. https://doi.org/10.1080/00207547708943107

Goyal, S. K. (1988). "A JOINT ECONOMIC-LOT-SIZE MODEL FOR PURCHASER AND VENDOR": A COMMENT. *Decision Sciences*, *19*(1), 236-241. https://doi.org/https://doi.org/10.1111/j.1540-5915.1988.tb00264.x

Hill, R. M. (1999). The optimal production and shipment policy for the single-vendor singlebuyer integrated production-inventory problem. *International Journal of Production Research*, *37*(11), 2463-2475. https://doi.org/10.1080/002075499190617

Hu, B., Meng, C., Xu, D., & Son, Y.-J. (2018). Supply chain coordination under vendor managed inventory-consignment stocking contracts with wholesale price constraint and fairness. *International Journal of Production Economics*, *202*, 21-31. https://doi.org/10.1016/j.ijpe.2018.05.009

Jiang, L., Wang, Y., & Liu, D. (2014). Logistics cost sharing in supply chains involving a third-party logistics provider. *Central European Journal of Operations Research*, *24*(1), 207-230. https://doi.org/10.1007/s10100-014-0348-5

Joglekar, P. N. (1988). Comments on "A Quantity Discount Pricing Model to Increase Vendor Profits". *Management Science*, *34*(11), 1391-1398. http://www.jstor.org/stable/2632001

Ke, Z., Zhang, Y., & Duan, D. (2024). Effect of centralized volume-based procurement of drugs on business performance of listed pharmaceutical enterprises. *Heliyon*, *10*(12), e33198. https://doi.org/10.1016/j.heliyon.2024.e33198

Khouja, M. (2003). Optimizing inventory decisions in a multi-stage multi-customer supply chain. *Transportation Research Part E: Logistics and Transportation Review*, *39*(3), 193-208. https://doi.org/10.1016/s1366-5545(02)00036-4

Krishnan, T. V., & Soni, H. (1997). Guaranteed profit margins: A demonstration of retailer power. *International Journal of Research in Marketing*, *14*(1), 35-56. https://doi.org/https://doi.org/10.1016/S0167-8116(96)00029-8

Lee, W. (2005). A joint economic lot size model for raw material ordering, manufacturing setup, and finished goods delivering.

Omega, *33*(2), 163-174. https://doi.org/10.1016/j.omega.2004.03.013

Lei, L., Wang, Q., & Fan, C. (2006). Optimal business policies for a supplier–transporter–buyer channel with a price-sensitive demand. *Journal of the Operational Research Society*, *57*(3), 281-289. https://doi.org/10.1057/palgrave.jors.2602000

Liu, R., Zhou, Z., Qin, Q., & Fan, B. (2022). Centralized drug procurement operation scheduling with a capacitated joint replenishment and delivery strategy: Evidence from China. *Computers & Industrial Engineering*, *172*. https://doi.org/10.1016/j.cie.2022.108584

Matsui, K. (2019). A supply chain member should set its margin later if another member's cost is highly uncertain. *European Journal of Operational Research*, *275*(1), 127-138. https://doi.org/10.1016/j.ejor.2018.11.027

Monahan, J. P. (1984). A Quantity Discount Pricing Model to Increase Vendor Profits. *Management Science*, *30*(6), 720-726. http://www.jstor.org/stable/2631751

Munson, C. L., & Rosenblatt, M. J. (2001). Coordinating a three-level supply chain with quantity discounts. *IIE Transactions*, *33*(5), 371-384. https://doi.org/10.1023/A:1011097012536

N.C.P.P.O, N. C. P. P. O. (2024). *National Centralized Procurement of Pharmaceuticals in China Document (GY-YD2024-1)*. (1). Retrieved from https://www.nhsa.gov.cn/col/col148/index.html

Simon, H. A. (1953). Notes on the Observation and Measurement of Political Power. *Journal of Politics*, *15*(4), 500-516.

Wang, S.-P., & Lee, W. (2013). A joint economic lot-sizing model for the hospital's supplier with capacitated warehouse constraint. *Journal of Industrial and Production Engineering*, *30*(3), 202-210. https://doi.org/10.1080/21681015.2013.805700

Whang, S. (1995). Coordination in operations: A taxonomy. *Journal of Operations Management*, *12*(3-4), 413-422. https://doi.org/https://doi.org/10.1016/0272-6963(95)00010-P

Zhang, R., Liu, J., & Qian, Y. (2022). Wholesale-price vs cost-sharing contracts in a green supply chain with reference price effect under different power structures. *Kybernetes*, *52*(5), 1879-1902. https://doi.org/10.1108/k-11-2021-1096