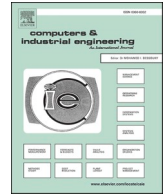




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## Advantages of 3PLs as healthcare supply chain orchestrators

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### ARTICLE INFO

#### Keywords:

Healthcare supply chain  
Third-party logistics  
Pricing  
Procurement service  
Coordination contracts

### ABSTRACT

Given the expansion of the COVID-19 cases and the average infection rate globally, constructing a robust healthcare supply chain system for the crisis is highly crucial. The third-party logistics providers (3PLs), who can match the market demand with reliable manufacturers worldwide, have emerged as orchestrators. In addition to the basic transportation and storage services, some 3PLs can also provide procurement assistance to relatively small retailers. To illustrate the value of the above-mentioned business model, we build a game-theoretic model to capture participants' optimal strategy in a healthcare supply chain consisting of a manufacturer, a 3PL provider, and a retailer. We also investigate the conditions where the performance in this business model outperforms the traditional model. It is concluded that the 3PL's positive effect appears when the decentralized supply chain is characterized by high logistics outsourcing costs and high-level price sensitivity. We further design an incentive mechanism that can coordinate the supply chain. Finally, a series of numerical experiments are carried out to demonstrate the effectiveness of our model.

## 1. Introduction

### 1.1. Background and motivation

The COVID-19 pandemic has unleashed a catastrophe at an unprecedented pace around the globe. The crisis leads to a surge in the transport of critical medical supplies in the affected areas (Ranney, Griffith, & Jha, 2020). Take the distribution of COVID-19 vaccines as an example: reliable shipping has to be quickly offered to cope with challenging tasks, i.e., high efficiency and strict temperature control. Thus, Pfizer, one of the most famous medical manufacturers, uses 3PLs (e.g., DHL, FedEx, and UPS) to deliver vaccines (Sagonowsky, 2020). In fact, 3PLs are crucial in medical supply stability not only for their expertise in transportation but also for their role as supply chain orchestrators through innovative procurement services.

Since the outbreak of COVID-19, most manufacturers—the upstream of healthcare supply chains—have not fully resumed work, which causes many organizations to scramble for alternative suppliers (GEP, 2020). Nevertheless, it is a thorny issue to find reliable manufacturers within a short period. Some 3PLs thus enable their accumulated manufacturer–retailer networks to quickly link manufacturers and retailers worldwide increase efficiency in the whole chain of activities by offering

“integrated logistics and procurement services” (shortened as ILPS hereafter). This novel business model has been accelerated as an emergency response strategy during the epidemic. For instance, the NHS (healthcare systems of the UK) recently signed contracts with DHL, Unipart, and Movianto to procure and ship protective equipment for infection control (Blackburn, 2020). Moreover, Pfizer proves that ILPS offered by UPS significantly streamlines the procurement process and avoids additional loading and unloading at distribution centers when shipping vaccines (Kaplan, 2020).

The benefits of ILPS include not only less delivery time, but more importantly, cost saving, improved service levels, reduced cash flow pressure, and fewer environmental footprints (Shi, Zhang, Arthanari, Liu, & Cheng, 2016). From the 3PLs' perspective, with ILPS, they in effect become supply chain orchestrators, which also allows them to capture an additional profit stream by offering value-added services (Chen, Cai, & Song, 2019). In the meantime, they can consolidate orders and rely on close partnerships to gain bargaining power with the suppliers. There has been a movement in the business world where 3PLs seek to generate substantial profit by specialized value-added services. One of these outstanding 3PLs, Eternal Asia, has pioneered an innovative procurement service. It has extended this brand-new business in the healthcare sector since 2017, accounting for almost 23% of its total

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<https://doi.org/10.1016/j.cie.2021.107628>

income (Eternal Asia, 2020), with revenue from healthcare services growing 26.86 percent year-on-year in 2020 to \$93.12 million (Eternal Asia, 2021). With this business model, *Eternal Asia* places orders to a manufacturer on behalf of a distributor and charges the retailer for both payment and logistics fees when the commodities are delivered. Similar scenarios are present at the *Biovac Institute* (a 3PL firm in South Africa) (Lydon, Raubenheimer, Arnot-Krüger, & Zaffran, 2015).

Although ILPS enjoys the above-mentioned advantages, the additional supply chain organizer results in "triple marginalization" and undermines the total profit of the supply chain. Motivated by the above evidence, therefore, this paper concentrates on the advantages of utilizing ILPS in the healthcare sector and examines the following research questions: does the occurrence of ILPS reduce the retail price and when? Is the manufacturer willing to leverage ILPS and when? What impact will the concentration of the supply chain have on the effectiveness of ILPS? We develop two models based on Stackelberg game theory. The first case is regarded as a benchmark in the field (*model T*), in which a retailer directly pays a manufacturer and a 3PL firm only provides transportation services. The second one extends the newsvendor model to a three-level supply chain (*model ILPS*), where a 3PL firm purchases products from a manufacturer and wholesales them to a retailer. Then, based on our results, we propose an effective contract combining altruistic preference and revenue sharing to maximize supply chain collaboration.

In each model, the retailer confronts a random demand sales season, which is highly dependent on the pricing factor, noting that this assumption is consistent with the reality of many situations, such as over-the-counter medicines and self-funded vaccines (e.g., HPV vaccines) (Zou et al., 2020). As discussed in Sarmah, De Giovanni, and De Giovanni (2020) and analyzed by Ching (2010), the price swings between patented and generic drugs are a key driving force of consumers' buying decisions in the pharmaceutical industry. One example that supports our model is the market for statins. Statins are among the most widely used drugs and are high in price. For example, Americans spent nearly \$20 billion on over 260 million prescriptions for statins in 2011. Statins can reduce the risk of heart attack or stroke by about one-third, but regular supplementation is needed because statins can reduce high cholesterol to some extent, despite the fact that they cannot cure it completely. After crossing the time threshold, many statins have lost patent protection, so many cheaper options have gradually become available. Physicians and patients often choose to reduce statin spending by replacing patent-protected drugs with generics since they are price-sensitive (Sacks, 2018).

The equilibriums of *model T* and *model ILPS* are compared in the following sub-section.

### 1.2. Contribution and paper organization

Our contribution to the current study can be mainly explained in three ways. First, according to the more and more popular practical applications, we develop a generic integrated service model for the healthcare supply chain consisting of a manufacturer, a 3PL provider, and a retailer. Then, we analyze and compare the performance of *model T* and *model ILPS*. The conditions where the *model ILPS* outperforms the traditional setting are revealed. We lastly designed an incentive mechanism to facilitate the three parties' coordination. It is found that the proposed contract allows the supply chain members to share risks involved in the overall trading process and mitigates "triple marginalization" in the decentralized system.

We organize the structure of this paper as follows. The related literature is briefly reviewed in Section 2. After introducing the general problem and notations in Section 3, we describe *model T* and *model ILPS* and release their equilibrium decisions in Section 4 and 5, respectively. In section 6, we propose a helpful incentive mechanism to coordinate the supply chain. In Section 7, we test the performance of utilizing ILPS by a series of numerical experiments. Section 8 gives the conclusion of the

paper.

## 2. Literature review

Our research is related to the role of 3PL as an intermediary in healthcare supply chain management. The use of 3PL in the healthcare context has grown dramatically in recent years (Abbasi, Saboury, & Jabalamei, 2021), which is seen as a strategic and organizational reform increasing efficiency and welfare subverting healthcare quality (Skipworth, Delbufalo, & Mena, 2020). There has been much research on 3PL. However, most of these papers concentrate on the 3PL providers specialize in transportation function only (e.g., Ülkü & Bookbinder, 2012; Jiang, Wang, & Yan, 2014; Balakrishnan & Natarajan, 2014; Santibanez-Gonzalez & Diabat, 2015; Giri & Sarker, 2017). Van Hoek (2000) suggests that 3PLs should consider expanding their services because expansion services can be seen as potential growth for its performance. Rajesh, Pugazhendhi, Ganesh, Muralidharan, and Sathiamoorthy (2011) showed that the 3PL firms are gradually starting to provide integrated transportation and other value-added services, including inventory control (Yao, Yue, Mukhopadhyay, & Wang, 2009; Zhang, Nault, & Tu, 2015), financial service (Chen & Cai, 2011), reverse logistics service (Suyabatmaz, Altekin, & Şahin, 2014). More recently, several studies have followed with interest in the role of the 3PL provider as a supply chain intermediary. Chen et al. (2019) demonstrate that when a 3PL acts as a supply chain intermediary, the entire supply chain can benefit from the ILPS role of the 3PL and the cash flow dynamics. Under this innovative and complicated scenario in a healthcare context, the current literature's research methods are usually either analytical or descriptive (Noon, Hankins, & Cote, 2003; Pinna, Carrus, & Marras, 2015; Rodrigues, Martins, Wanke, & Siegler, 2018). Skipworth et al. (2020) use a theoretical model to compare the performance of public-to-public ILPS and public-to-private ILPS. They showed through case analysis that the cost-effectiveness of both strategies improved. Note that we are different from the study on group purchasing organizations (GPOs), which have been given a more detailed description by Belavina and Girotra (2012) and Mustafa and Potter (2009). In this research, we build a model-based economic evaluation to assess the optimal decisions and respective performances utilizing ILPS in a healthcare supply chain where the 3PL provider offers procurement service on behalf of a distributor.

Most of the related research under the ILPS focuses on the 3PL provider's financing function (Hua, Sun, Liu, & Zhai, 2021). For instance, Huang, Fan, and Wang (2019) studied the impact of transportation costs on the supply chain when a 3PL company provided a financing service. They found that if transportation costs met certain conditions, they could increase the supply chain's total profitability. Wang, Yang, Zhuo, and Xiong (2019) also focused on integrated logistics and financial services, but they are more concerned about the impact of risk appetite and demand volatility. They found that the 3PL firm preferred a risk-averse manufacturer. Unlike the above papers, which investigated the advantages of cash flow and financing service brought by the 3PL provider, we attempt to study how the procurement service itself influences the supply chain decisions and profits, mainly focusing on the advantages of 3PL as a supply chain intermediary. Moreover, to capture the healthcare products' character, we suppose that the market demand is sensitive to the selling price, an endogenous decision variable. This is highly in relation to the consumer's the price sensitivity to healthcare products, especially when there are a large number of overpriced products and low-cost alternatives in the healthcare market due to its particularity (Sacks, 2018; Sarmah et al., 2020).

Our research is also related to studies on supply chain management of healthcare products (e.g., drug, vaccine, PPE). In traditional healthcare supply chain management, Uthayakumar and Priyan (2013) developed an inventory model determining delivery times and available stock quantity in a healthcare supply chain that included a pharmaceutical company and a hospital. Zheng et al. (2006) identified

implementing new information technological alternatives, such as information system integration, radio frequency identification devices (RFID), for future studies to improve healthcare supply chain management while adding value. Walker, Di Sisto, and McBain (2008), Rahimnia and Moghadasian (2010), Bhakoo and Choi (2013), and Kogan, Leu, and Chernonog (2014) analyzed the cases of healthcare companies to evaluate how different factors of supply chain management affect the supplier or buyer to formulate winning healthcare supply chain strategic plan (Kwon, Kim, & Martin, 2016). A few empirical studies show that the traditional healthcare supply chain management should be transformed into ILPS centralized outsourcing innovation management for improving organizational performance (e.g., Pinna et al., 2015; Skipworth et al., 2020; Rodrigues et al., 2018).

However, the participation of the 3PL provider may bring terrible “triple marginalization” (Chen et al., 2019). Hence, the incentive mechanism to coordinate the three players involved in the healthcare supply chain is another topic investigated in this paper. Few scholars have focused on the characteristics of coordination strategies in the healthcare supply chain (Ma, Gong, & Jin, 2019). With regard to the complexity and challenging aspects of specific contract designs, there are relatively little researches on coordination between more than two parties. Sher, Kim, Banerjee, and Paz (2018) coordinate the supply chain for common items in the defense, electronics, and medical industries through common replenishment times, reducing the cost of a supply chain consisting of a single supplier and  $n$  purchasers. Fu, Ke, Lian, and Zhang (2021) design a cost allocation scheme to coordinate a supplier, a retailer, and a 3PL firm supported by external equity financing to save costs. Our study identifies 3PLs as critical players in the healthcare supply chain. Besides, Shi, Arthanari, and Wood (2017) take a static approach and find that only manufacturers cooperate with 3PL, who then would agree to provide sourcing services to retailers. This manifestation is referred to as altruistic preference. It is commonly interpreted as the Stackelberg game leader’s caring for the interests of the dominated party for reasons of long-term sustainability, corporate social responsibility, or other reasons (Wang, Yu, Jin, & Mao, 2021). There is now widespread research evidence that supply chain decisions are influenced by the altruistic preferences of decision makers (Ma, Hu, & Yao, 2021). Our proposed coordination scheme is distinguishable from previous research, as we incorporate the manufacturer’s altruistic preference into a revenue-sharing contract between the 3PL provider and the retailer.

### 3. Problem description

Before the basic assumptions and the description of the supply chain problem, the notation used throughout this paper is shown below (Table 1):

We take a healthcare supply chain into consideration, where a single healthcare product is traded within a season, i.e., newsvendor setup. It is assumed that the demand in the medical market is randomized naturally and typically influenced by the selling price, whereas the market price and risks are endogenous. This is more consistent with evidence on physician-prescribing behaviors (e.g., see Sacks, 2018) and patients’ consumption choices (Denoyel, Alfandari, & Thiele, 2017; Sarmah et al., 2020). Thus, the market demand depends on the selling price and has the following multiplicative functional-form (Petruzzi & Dada, 1999; Wang, 2006; Chen & Bell, 2011):

$$D(p, \varepsilon) = \alpha(p) \cdot \varepsilon = ap^{-b} \cdot \varepsilon,$$

where  $a$  represents the scale factor in determining the potential market scale,  $b$  is referred to as the price sensitivity, and  $\varepsilon$  is a random variable that describes the fluctuations in market demand. Moreover,  $f(\cdot)$ ,  $F(\cdot)$ , and  $\bar{F}(\cdot)$  are denoted to the PDF, CDF, and complementary CDF, respectively. It is noted that  $F(\cdot)$  is differentiable and increasing. The failure rate of  $\varepsilon$  is defined as  $h(\cdot) = f(\cdot)/\bar{F}(\cdot)$ , where  $\varepsilon \in [A, B]$ . Our

**Table 1**  
List of notations.

Notation	Description
<b>Parameters</b>	
$c_l$	The unit operation cost of the 3PL provider
$c_m$	The unit production cost of the manufacturer
$t$	The unit logistics outsourcing cost paid by the manufacturer, $t > c_l$
$\theta$	The manufacturer’s altruistic preference coefficient
$\eta$	The 3PL’s profit distribution ratio under the sharing revenue
$a$	The market demand scale
$b$	The sensitivity of the market demand to the selling price, $b > 1$
$\varepsilon$	Random fluctuation of the demand, $\varepsilon \in [A, B]$ , where $A$ and $B$ are positive constants
$h(x)$	The failure rate function of $\varepsilon$ , i.e., $h(x) = f(x)/\bar{F}(x)$
$D(p, \varepsilon)$	The market demand
$\Pi_r$	The expected profit of the retailer
$\Pi_l$	The expected profit of the 3PL provider
$\Pi_m$	The expected profit of the manufacturer
$\Pi$	The total expected profit of the supply chain
<b>Index</b>	
$T$	Indicating Scenario 1
$I$	Indicating Scenario 2
$C$	Indicating Scenario 3
<b>Decision variables</b>	
$p$	The retailer’s unit selling price
$q$	The retailer’s order quantity
$s$	The unit ILPS price charged by the 3PL, $s > w + c_l$
$w$	The manufacturer’s unit wholesale price, $w > c_m$

attention is paid to the demand distributions with an increasing failure rate (IFR), i.e.,  $h'(\cdot) > 0$ . In the following sections, we study how a 3PL provider offering ILPS, who is more of a distributor, affects each supply chain member’s decision. Note that a three-echelon Stackelberg game is adopted to derive the optimal decisions under this framework, where the leader is the manufacturer, the sub-leader is the 3PL provider, and the retailer acts as the follower. Also, it is supposed that the salvage value of any product left unsold is null for simpleness and convenience, and the shortage cost is not considered as well.

**Assumption 1.** The following conditions are assumed to be satisfied by the demand function:

- (1)  $b > 1$ , a price-elastic healthcare product is focused on;
- (2)  $\varepsilon$  has an increasing failure rate (IFR).

We next introduce the two scenarios mentioned above separately, including the sequence of events and decisions to be made by all the participants.

- **Scenario 1 (model  $T$ )** is under a traditional supply chain setting, where a retailer has only one opportunity to order directly from a manufacturer to meet the uncertain demand in the sales season. The sequence of decision-making events is shown as follows (see Fig. 1): The manufacturer, as the leader of the Stackelberg game, first determines the wholesale price  $w_T$  after considering the unit production cost  $c_m$  and logistics outsourcing cost  $t$ . Subsequently, the retailer decides the selling price  $p_T$  and order quantity  $q_T$  to maximize its profit.
- **Scenario 2 (model ILPS)** extends the above model to a three-level supply chain, including a manufacturer, a 3PL provider, and a retailer. Fig. 2 illustrates the sequence of events: The manufacturer first enters into a price-only procurement contract with 3PL at wholesale price  $w_l$ . After that, the 3PL provider decides the ILPS price  $s$ , according to  $w_l$  and the unit logistics operation cost  $c_l$ . Lastly,

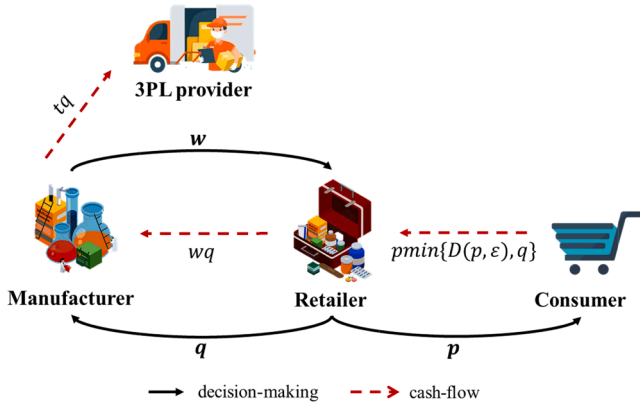


Fig. 1. Traditional supply chain setting (Scenario 1).

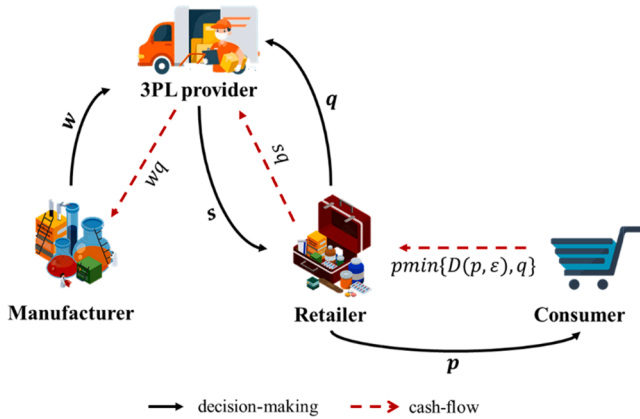


Fig. 2. ILPS based supply chain setting (Scenario 2).

the retailer determines the optimal order quantity  $q_I$ , and sets the selling price  $p_I$  to confront the price-dependent random demand.

**Assumption 2.** Suppose the 3PL provider satisfies the following conditions:

- (3)  $t > c_i$ ;
- (4)  $s > w + c_i$ .

If Assumption 2 is not satisfied, there is no condition for positive profitability of the 3PL provider, or the occurrence of 3PL is always redundant.

**4. The benchmark cases**

Within this section, we explore the manufacturer’s and the retailer’s optimal decisions in Scenario 1. As a starting point, for any given wholesale price  $w_T$ , the retailer is faced with a joint pricing-quantity decision. In particular, the retailer decides the optimal price  $p_T$  and the ordering quantity  $q_T$  so as to maximize its expected profit  $\Pi_r^T$

$$\Pi_r^T(p_T, q_T) = p_T E\{\min(q_T, D)\} - w_T q_T = (p_T - w_T)q_T - p_T E\{(q_T - D)^+\}. \tag{1}$$

For the convenience of exposition, we introduce the following “stocking factor” (see Petruzzi & Dada, 1999):

$$z = q/\alpha(p) = q/ap^{-b}. \tag{2}$$

Then, we can convert the problem of optimizing  $(p_T, q_T)$  into that of

optimizing  $(p_T(z))$  and rewrite the retailer’s profit function as

$$\begin{aligned} \Pi_r^T(p_T, z) &= (p_T - w_T)q_T - p_T \int_A^{q_T/\alpha(p_T)} (q_T - D)f(x)dx \\ &= (p_T - w_T)z\alpha(p_T) - p_T \int_A^z [z\alpha(p_T) - \alpha(p_T)x]f(x)dx, \\ &= \alpha(p_T) \left[ (p_T - w_T)z - p_T \int_A^z (z - x)f(x)dx \right] \end{aligned} \tag{3}$$

**Theorem 1.** The optimal stocking factor  $z^*$  is the unique solution to the following equation:

$$\frac{z\bar{F}(z)}{z - \int_A^z (z - x)f(x)dx} = \frac{b - 1}{b}. \tag{4}$$

Theorem 1 shows that the optimal stocking factor is determined by the price sensitivity  $b$  and the distribution of the random factor  $\epsilon$ , and is independent of other parameters.

**Proof.** According to the method introduced by Zabel (1970), we first obtain the optimal  $p^*(z)$  with a given  $z$ , and then substitute it into the objective function to obtain the optimal  $z^*$ . Taking the first derivative of  $\Pi_r^T(p_T)$  concerning  $p_T$ , we have

$$\frac{\partial \Pi_r^T(p_T)}{\partial p_T} = \frac{\alpha(p_T)}{p_T} \left\{ bz w_T - p_T(b - 1) \left[ z - \int_A^z (z - x)f(x)dx \right] \right\}$$

The unique optimal selling price is obtained from the first-order condition above, i.e.,  $p_T^*(z) = \frac{bz w_T}{(b-1) \left[ z - \int_A^z (z-x)f(x)dx \right]}$ . Then we substitute

$p_T^*(z)$  into Eq. (3). The following first-order conditions must be met for the optimal stocking factor to maximize  $\Pi_r^T(p_T^*(z), z)$ .

$$\frac{d\Pi_r^T(p_T^*(z), z)}{dz} = \frac{\alpha(p_T^*)w_T \left\{ bz\bar{F}(z) - (b - 1) \left[ z - \int_A^z (z - x)f(x)dx \right] \right\}}{(b - 1) \left[ z - \int_A^z (z - x)f(x)dx \right]} = 0,$$

from this we can prove that the optimal stocking factor must fulfil Eq. (4). Next, we show the uniqueness of  $z^*$ . Let

$$R(z) = bz\bar{F}(z) - (b - 1) \left[ z - \int_A^z (z - x)f(x)dx \right],$$

where  $z \in [A, B]$ . We take the first and second derivatives of  $R(z)$  with regard to  $z$ , and obtain

$$\begin{aligned} R'(z) &= \bar{F}(z)[1 - zh(z)b]; \\ R''(z) &= -h(z)R'(z) - b\bar{F}(z)[h(z) + zh'(z)], \end{aligned}$$

where  $h(z)$  increases in  $z$ . When  $R'(z) = 0$ , there exists  $R''(z) < 0$ , i.e.,  $R(z)$  increases before  $z$  satisfying  $R'(z) = 0$  and decreases after, and hence  $R(z)$  is unimodal. As  $R(A) = A > 0$  and  $R(B) = -(b - 1)B < 0$ , it is obvious that  $R(z) = 0$  has a unique solution available in  $[A, B]$ ; thus,  $z^*$  is determined uniquely by Eq. (4). It is also evident that for  $z < z^*$ ,  $R(z) > 0$  and therefore  $\partial \Pi_r^T(p_T^*, z)/\partial z > 0$ ; for  $z > z^*$ ,  $R(z) < 0$  and therefore  $\partial \Pi_r^T(p_T^*, z)/\partial z < 0$ . Thus,  $\Pi_r^T(p_T, z)$  is also unimodal in  $z$ , suggesting that  $z^*$  is the unique solution. Additionally, we can easily obtain

retailer’s optimal decisions in this stage,  $p_T^* = \frac{w_T}{\bar{F}(z^*)}$ ,  $q_T^* = \alpha z^* \left[ \frac{\bar{F}(z^*)}{w_T} \right]^b$ ,

based on Theorem 1 together with Eqs. (2) and (4).

Subsequently, the manufacturer endeavors to decide on the appropriate wholesale price  $w_T$  to maximize its revenue. The manufacturer’s expected profit is:

$$\Pi_m^T(w_T) = (w_T - c_m - t)q_T \tag{5}$$

**Theorem 2.** In Scenario 1, there exist the equilibrium decisions,  $(p_T^*, q_T^*, w_T^*)$ , as follows:

$$w_T^* = \frac{b(c_m + t)}{b - 1} \tag{6}$$

$$p_T^* = \frac{b(c_m + t)}{(b - 1)\bar{F}(z^*)} \tag{7}$$

$$q_T^* = az^* \left( \frac{(b - 1)\bar{F}(z^*)}{b(c_m + t)} \right)^b \tag{8}$$

Theorem 2 is not so hard to prove according to Theorem 1 that we omit it here. The theorem implies that, under the traditional supply chain setting, the manufacturer’s optimal wholesale price, the optimal selling price, and order quantity determined by the retailer have a close relationship with both the price sensitivity of the market demand and the manufacturer’s logistics outsourcing cost. We can see that  $p_T^* > w_T^*$ , and the retailer’s optimal selling price  $p_T^*$  is proportional to the manufacturer’s optimal wholesale price  $w_T^*$ . This ensures that the retailer always has a positive expected profit. The incremental price (as relative to the wholesale price) depends on the optimal stocking factor  $z^*$ : the larger the  $z^*$ , the higher the optimal retail price.

**5. The value of 3PL purchasing**

This section introduces a 3PL provider into the supply chain, which undertakes the dual business of procurement and transportation. We first explore the retailer’s, the 3PL provider’s, and the manufacturer’s optimal decisions in a decentralized supply chain system. To study whether the 3PL benefits the supply chain and reduces the final price, we then make a comparison of equilibrium decisions and profits in Scenario 1 and 2. This section is also intended to highlight managerial insights based on the above comparison and analysis.

**5.1. Equilibrium analysis in Scenario 2**

First, the retailer also faces a joint pricing-quantity decision problem, as described in the previous section. In Scenario 2, where a 3PL provider offers the ILPS, the profit of the retailer is:

$$\begin{aligned} \Pi_r^I(q_I, p_I) &= p_I E\{\min(q_I, D)\} - s_I q_I = (p_I - s_I)q_I - p_I E\{(q_I - D)^+\}, \\ \text{then } \Pi_r^I(p_I, z) &= \alpha(p_I) \left[ (p_I - s_I)z - p_I \int_A^z (z - x)f(x)dx \right] \end{aligned} \tag{9}$$

Similar to the analysis in the benchmark cases, we are able to derive the optimal retailer’s decisions as  $p_I^* = \frac{s_I}{\bar{F}(z^*)}$ ,  $q_I^* = az^* \left[ \frac{\bar{F}(z^*)}{s_I} \right]^b$ . When the retailer purchases products through the 3PL provider, the 3PL has to bear all logistics operation cost  $c_l q_I^*$  during each transaction and transfers the payment  $w_I q_I^*$  to the manufacturer. It is essential for the 3PL provider to determine appropriate ILPS price  $s_I$  according to the logistics and procurement costs to maximize its expected profit:

$$\Pi_I^I(s_I) = (s_I - c_l - w_I)q_I^* \tag{10}$$

Finally, we are prepared to seek the manufacturer’s best wholesale price decision. The profit function for the manufacturer is given first.

$$\Pi_m^I(w_I) = (w_I - c_m)q_I^* \tag{11}$$

**Theorem 3.** In Scenario 2, there exist the equilibrium decisions,  $(p_I^*, q_I^*, s_I^*, w_I^*)$ , as follows:

$$w_I^* = \frac{b(c_m + c_l)}{b - 1} - c_l \tag{12}$$

$$s_I^* = \frac{b^2(c_m + c_l)}{(b - 1)^2} \tag{13}$$

$$p_I^* = \frac{b^2(c_m + c_l)}{(b - 1)^2 \bar{F}(z^*)} \tag{14}$$

$$q_I^* = az^* \left( \frac{(b - 1)^2 \bar{F}(z^*)}{b^2(c_m + c_l)} \right)^b \tag{15}$$

Theorem 3 can be proved by backward induction. Specifically, similar to the analysis in the benchmark cases, we are able to derive the optimal decisions for the three players in this supply chain setting. The optimal stocking factor is still obtained from Eq. (4). It shows that *model ILPS* reduces the wholesale price of the manufacturer since it is obvious to see that  $w_I^* > w_T^*$ . The difference between Eqs. (6) and (12) proves that the manufacturer’s wholesale price depends on 3PL’s operating costs (assuming all other parameters remain unchanged), so 3PL needs to reduce its own operating costs as much as possible in exchange for a greater possibility for the manufacturer to work with it. In addition, there is a multiplicative relationship of  $\bar{F}(z^*)$  between  $p_I^*$  and  $s_I^*$ . The inequality  $p_I^* > s_I^*$  and  $s_I^* > w_I^*$  guarantee positive profits for the retailer and 3PL, respectively.

**5.2. The comparison of the equilibrium results**

We next compare the optimal decisions and performances in these two settings to derive managerial insights. Based on the above Theorems, the characteristics of the relationship between the retailer’s pricing and order decisions in Scenario 1 and 2 are summarized below.

**Corollary 1.** If  $\frac{b}{b-1} < \frac{c_m+t}{c_m+c_l}$ , then  $p_I^* < p_T^*$ ,  $q_I^* > q_T^*$ .

Corollary 1 shows that when the price sensitivity and the logistics outsourcing cost together to satisfy the given inequality, the retailer is prompted to reduce the selling price to stimulate market demand. Also, there is an incentive for retailers to order more from 3PL. Furthermore, we investigate when the manufacturer, representing the supply chain leader, is willing to introduce the ILPS offered by the 3PL firm into the system.

**Corollary 2.** (i) When  $c_l < t \leq \frac{b}{b-1}(c_l + c_m) - c_m$ , there exist  $p_I^* > p_T^*$  and  $\Pi_m^I < \Pi_m^T$ ;

(ii) When  $\frac{b}{b-1}(c_l + c_m) - c_m < t \leq \left(\frac{b}{b-1}\right)^{\frac{b}{b-1}}(c_l + c_m) - c_m$ , there exist  $p_I^* < p_T^*$  and  $\Pi_m^I < \Pi_m^T$ ;

(iii) When  $t > \left(\frac{b}{b-1}\right)^{\frac{b}{b-1}}(c_l + c_m) - c_m$ , there exist  $p_I^* < p_T^*$  and  $\Pi_m^I > \Pi_m^T$ .

Corollary 2 demonstrates that the range of values of logistics outsourcing cost  $t$  can be divided into three intervals due to the following two boundary values:  $t_{low} = \frac{b}{b-1}(c_l + c_m) - c_m$  derived from Corollary 1 (i.e.,  $q_I^* = q_T^*$ ),  $t_{up} = \left(\frac{b}{b-1}\right)^{\frac{b}{b-1}}(c_l + c_m) - c_m$  derived from  $\Pi_m^I(q_I^*) = \Pi_m^T(q_T^*, t)$ . In each of intervals the performance of using ILPS is distinctive. Specifically, we conclude the significant results as follows:

- (1) When  $t \in \left(c_l, \frac{b}{b-1}(c_l + c_m) - c_m\right]$ , ILPS instead increases the selling price, even damaging the profit of the manufacturer;

- (2) When  $t \in \left( \frac{b}{b-1}(c_l + c_m) - c_m, \left( \frac{b}{b-1} \right)^{\frac{b}{b-1}}(c_l + c_m) - c_m \right]$ , the retailer is induced by ILPS to reduce the selling price, but also causing the lower profit of the manufacturer, i.e., the manufacturer has no incentive to grant distribution rights to the 3PL provider;
- (3) Only when  $t > \left( \frac{b}{b-1} \right)^{\frac{b}{b-1}}(c_l + c_m) - c_m$ , ILPS can reach the two goals concurrently, i.e., making the retailer reduce the selling price and being advantageous to the manufacturer's profit.

As analyzed above, we can derive the manufacturer's, the 3PL provider's, and the retailer's optimal strategies under a decentralized system. Corollary 1 and 2 imply that ILPS sometimes may not prompt the retailer to reduce the selling price and even cause the leader's loss. In practice, the sum of the profits of the manufacturer, 3PL provider and retailer is usually smaller than the aggregate profit of a centralized supply chain. This is due to the fact that the goal of a decentralized system is to maximize individual profits without regard to supply chain operational goals.

### 6. Supply chain coordination analysis

In this section, we first develop an extended model to describe the centralized scenario. Then we prove that it is necessary to design a coordination mechanism to make each participant's respective strategy consistent with the whole system's optimal strategy.

#### 6.1. Optimal centralized decisions

In a centralized system, all the participants act in a coordinated manner with the common goal of maximizing the total expected profit of the supply chain. Under this framework, the wholesale price and ILPS price become internal parameters. The only decisions that need to be made are the order quantity and the selling price. The expected profit function can be given as

$$\begin{aligned} \Pi^l(p, q) &= pE\{\min(q, D)\} - (c_l + c_m)q = [p - (c_l + c_m)]q - pE\{(q - D)^+\}, \\ \text{then } \Pi^l(p, z) &= \alpha(p) \left\{ [p - (c_l + c_m)]z - p \int_A^z (z - x)f(x)dx \right\} \end{aligned} \tag{16}$$

We can also derive the optimal decisions in backward order based on the optimal stocking factor generated from Eq. (4).

**Theorem 4.** *In the centralized supply chain system, the optimal selling price and order quantity are:*

$$p^* = \frac{bz^*(c_l + c_m)}{(b - 1) \left[ z^* - \int_A^{z^*} (z^* - x)f(x)dx \right]} \tag{17}$$

$$q^* = \alpha z^* \left( \frac{\bar{F}(z^*)}{c_l + c_m} \right)^b \tag{18}$$

We present the following corollary that compares the optimal decisions and performances of the decentralized and centralized supply chain systems.

**Corollary 3.** *The optimal selling price in the decentralized system is higher than the optimal selling price in the centralized system, while the optimal order quantity is exactly the opposite, i.e.,  $p^* < p_l^*$ ,  $q^* > q_l^*$ .*

For the given price sensitivity with  $b > 1$ , we can easily have

$$\frac{p^*}{p_l^*} = \left( \frac{b - 1}{b} \right)^2 < 1, \quad \frac{q^*}{q_l^*} = \left( \frac{b}{b - 1} \right)^{2b} > 1.$$

Which indicates that these ratios depend only on the price sensitivity of the market demand. It is evident that  $[(b - 1)/b]^2$  is increasing in  $b \in (1, +\infty)$ , and  $[b/(b - 1)]^{2b}$  is decreasing in  $b$ . Hence, the selling price sensitivity of demand is lower, the optimal price of a centralized system is closer to the optimal price of a decentralized system.

We further investigate the advantage of centralization on the expected profit. As described above, the profits of the manufacturer, the 3PL provider, and the retailer are denoted as  $\Pi_m^l$ ,  $\Pi_l^l$  and  $\Pi_r^l$ , respectively. We define  $(\Pi_m^l + \Pi_l^l + \Pi_r^l)$  as the expected profit of the decentralized system and  $\delta$  as the magnitude of the expected loss due to the absence of coordination among the participants. We have

$$\delta = 1 - \frac{\Pi_m^l + \Pi_l^l + \Pi_r^l}{\Pi^c} = 1 - \left( \frac{b - 1}{b} \right)^{2b},$$

which shows that the profit loss  $\delta$  increases in  $b$ , i.e., the more sensitive the market demand is to the pricing change, the greater the profit loss becomes because of the absence of a coordination mechanism.

Therefore, based on the above analysis, we find that when a manufacturer has an altruistic preference that values the interests of its partners, it can reduce the profit loss in the supply chain. However, this unilateral altruistic preference of the manufacturer does not necessarily benefit the supply chain. The reason is that the manufacturer may give the 3PL a lower wholesale price in consideration of the partnership, but the 3PL aiming to maximize its own interest would still charge the retailer as much as possible for its procurement services. If the retailer does not benefit from the manufacturer's altruistic preference would naturally have no incentive to reduce retail prices to stimulate market demand. For this reason, we consider that when the 3PL shares revenue with the retailer, the manufacturer with altruistic preference would value the interests of their partners and thus increase profits throughout the supply chain.

#### 6.2. Design of coordination mechanism

Coordination mechanisms play a crucial role in collaborating for members' gains and achieving the supply chain's objective. The key of our coordination mechanism is to incentivize the downstream and the upstream of the supply chain to go beyond the levels found in the traditional system when using ILPS. To this end, upstream members are often willing to assume a portion of the risks of downstream members. Specifically, under our model setting, the manufacturer faces the risk that the use of ILPS brings higher retail price due to "triple marginalization". Besides, the retailer confronts an uncertain price-sensitive market demand, and the 3PL provider determines the service price according to the logistics operation costs and procurement costs.

Therefore, we propose a coordination mechanism that can lead to a mutual sharing of the respective risks among the three parties. We suppose that the manufacturer is not directly involved in the contract between the 3PL and the retailer. Being the leader, he must monitor the activities among the participants and design mechanisms so as to improve the performance of the system.

- **Scenario 3 (model ILPS-C)** employs a joint contract mechanism viz. revenue sharing (RS) between the 3PL provider and the retailer, along with altruistic preference (AP) between the manufacturer and the 3PL provider. In particular, the manufacturer takes the overall utility of itself and its partner as the decision-making goal with altruistic preference. We use altruistic preference  $\theta$  to describe the manufacturer's behavior to highlight its partner's profit based on Hua, Liu, Cheng, and Zhai (2019). The manufacturer's level of importance attaches to the 3PL provider is monotonically increasing in the range of  $\theta \in [0, 1)$  (see Fig. 3).

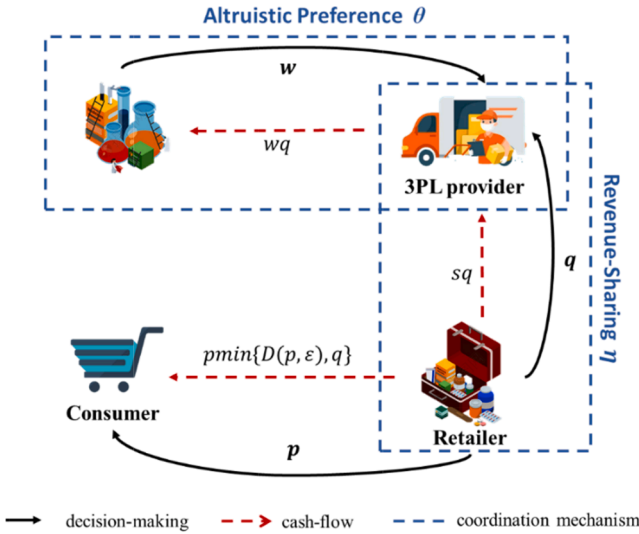


Fig. 3. Supply chain coordination mechanism (Scenario 3).

6.3. Equilibrium analysis in Scenario 3

The RS contract with altruistic preference run-in a sequential manner. Initially, the manufacturer consults with the 3PL provider to determine a wholesale pricing policy  $w_c$ . The retailer then determines the joint pricing-quantity  $(p_c, q_c)$  strategy after negotiating with the 3PL provider. The retailer and 3PL play as a centralized decision-maker to game with the manufacturer, and we mainly analyse the strategies of this centralized decision-maker and the manufacturer in this scenario.

Under RS contract, the retailer keeps  $(1 - \eta)$  ( $0 \leq \eta < 1$ ) of its share of the revenue for itself and agrees to allocate  $\eta$  share to the 3PL provider, we can rewrite the retailer's profit as:

$$\Pi_r^C(p_c, q_c) = (1 - \eta)p_c E\{\min(q_c, D)\} - s_c q_c, \tag{19}$$

and the 3PL provider's profit as:

$$\Pi_l^C(s_c) = \eta p_c E\{\min(q_c, D)\} + (s_c - c_l - w_c)q_c. \tag{20}$$

Thus, the total profit where the 3PL and the retailer are taken as a whole is:

$$\begin{aligned} \Pi_{sum}^C(p_c, q_c) &= p_c E\{\min(q_c, D)\} - (c_l + w_c)q_c, \\ \text{then } \Pi_{sum}^C(p_c, z) &= \alpha(p_c) \left[ (p_c - w_c - c_l)z - p_c \int_A^z (z - x)f(x)dx \right] \end{aligned} \tag{21}$$

Based on the rule of RS and the above equations, we can easily derive  $s_c = (1 - \eta)(w_c + c_l)$ .

**Corollary 4.** *The revenue sharing ratio must satisfy  $\frac{(b-1)^{2b-1}}{b^b(b-1+\theta)^{b-1}} \leq \eta \leq 1$  –  $\left[ \frac{(b-1)^2}{b(b-1+\theta)} \right]^{b-1}$  based on  $\Pi_r^C(p_c^*, q_c^*) \geq \Pi_r^I(p_c^*, q_c^*)$ ,  $\Pi_l^C(p_c^*, q_c^*) \geq \Pi_l^I(p_c^*, q_c^*)$  to ensure that both the retailer and the 3PL provider can get greater profits than those in the decentralized system.*

We are also interested in how altruistic preference affects the revenue sharing ratio. We find that the interval between the minimum ratio (denoted as  $\eta_{min}$ ) and the maximum ratio (denoted as  $\eta_{max}$ ) is increasing in  $\theta$ , which is given by:

$$\eta_{max} - \eta_{min} = 1 - \frac{(b-1)^{2b-2}(2b-1)}{b^b(b-1+\theta)^{b-1}}$$

Furthermore, when the retailer shares revenue with the 3PL provider, i.e., these two players as a centralized decision-maker agree with the RS contract by consensus, we therefore neglect to analyse the impact of  $\eta$  within the following decision-making process. The expected utility

function of the manufacturer with altruistic preference  $\theta$  is given by:

$$U(\Pi_m^C) = \Pi_m^C + \theta \Pi_{sum}^C = [w_c(q_c) - c_m]q_c + \theta \frac{w_c(q_c) + c_l}{b-1} q_c, \tag{22}$$

where  $w_c(q_c) = \bar{F}(z)(az/q_c)^{1/b} - c_l$  derived from Eq. (21)

Then, taking first and second order derivatives concerning the order quantity  $q_c$  on both sides of Eq. (22) and by some algebraic transformations, similar to the analysis in the benchmark cases, we can obtain the optimal operational strategies for each participant.

**Theorem 5.** *In Scenario 3, there exist the equilibrium decisions,  $(p_c^*, q_c^*, w_c^*)$ , as follows:*

$$w_c^* = \frac{bc_m + (1 - \theta)c_l}{b - 1 + \theta}. \tag{23}$$

$$p_c^* = \frac{b(c_m + c_l)}{(b - 1 + \theta)\bar{F}(z^*)}. \tag{24}$$

$$q_c^* = az^* \frac{[(b - 1 + \theta)\bar{F}(z^*)]^b}{[b(c_m + c_l)]^b}. \tag{25}$$

**Corollary 5.** *The RS contract with altruistic preference would induce the coordinated supply chain to achieve a lower selling price and a greater order quantity than those of the two decentralized systems, i.e.,  $p_c^* < p_l^*$ ,  $q_c^* > q_l^*$  and  $p_c^* < p_r^*$ ,  $q_c^* > q_r^*$ .*

As we might expect, the coordinated system outperforms those of the decentralized systems. Recall that we derive  $\frac{p_c^*}{p_l^*} = \left(\frac{b-1}{b}\right)^2 < 1$ ,  $\frac{q_c^*}{q_l^*} = \left(\frac{b}{b-1}\right)^{2b} > 1$ . For the given price sensitivity and altruistic preference, we can also have

$$\begin{aligned} \frac{p_c^*}{p_l^*} &= \frac{(b-1)^2}{b(b-1+\theta)} < 1, \quad \frac{q_c^*}{q_l^*} = \left[ \frac{b(b-1+\theta)}{(b-1)^2} \right]^b > 1, \quad \frac{p_r^*}{p_c^*} \\ &= \left[ \frac{b(b-1+\theta)(c_m+t)}{(b-1)(c_m+c_l)} \right] > 1, \quad \frac{q_r^*}{q_c^*} = \left[ \frac{(b-1)(c_m+c_l)}{(b-1+\theta)(c_m+t)} \right]^b < 1. \end{aligned}$$

It is clear that the larger  $\theta$ , the closer the performance under our designed coordination mechanism is to the centralized system. We summarize the optimal decisions under these three scenarios in Table 2.

An exciting finding can be derived from Theorem 5. Taking the derivative with respect to the manufacturer's altruistic preference  $\theta$  on both sides of Eqs. (23)–(25) and by some algebraic transformations, we obtain  $\frac{dp_c^*(\theta)}{d\theta} < 0$ ,  $\frac{dq_c^*(\theta)}{d\theta} > 0$  and  $\frac{dw_c^*(\theta)}{d\theta} < 0$ , respectively. Thus, only  $q_c^*(\theta)$  is increasing in  $\theta$  but  $p_c^*(\theta)$  and  $w_c^*(\theta)$  decreasing in  $\theta$ . This implies that the more important the altruistic manufacturer attaches to its partners, the further the retailer will bring down its selling price under the RS contract. As a result, the increase in market demand due to the decreased price brings more customer orders.

However, in the meanwhile, the manufacturer confronts the lower wholesale price  $w_c^*$  under this condition to share the risk of the downstream supply chain members. To this end, analyzing what impact the level of altruistic preference has on the manufacturer's profit is important. According to the above, we can easily have the following equations:

$$\Pi_m^T(w_r^*(t)) = \Pi_m^T(t) = \frac{c_m + t}{b-1} q_T^*, \tag{26}$$

$$\Pi_m^C(w_c^*(\theta)) = \Pi_m^C(\theta) = \frac{(1-\theta)(c_m+c_l)}{b-(1-\theta)} q_c^*. \tag{27}$$



**Table 2**  
Summary of optimal decisions in different scenarios.

	Decentralized systems		Coordinated system
	Scenario 1	Scenario 2	Scenario 3
Wholesale price, $w^*$	$\frac{b(c_m + t)}{b - 1}$	$\frac{b(c_m + c_l)}{b - 1} - c_l$	$\frac{bc_m + (1 - \theta)c_l}{b - 1 + \theta}$
ILPS price, $s^*$	N/A	$\frac{b^2(c_m + c_l)}{(b - 1)^2}$	$(1 - \eta) \left[ \frac{bc_m + (1 - \theta)c_l}{b - 1 + \theta} + c_l \right]$
Selling price, $p^*$	$\frac{b(c_m + t)}{(b - 1)\bar{F}(z^*)}$	$\frac{b^2(c_m + c_l)}{(b - 1)^2\bar{F}(z^*)}$	$\frac{b(c_m + c_l)}{(b - 1 + \theta)\bar{F}(z^*)}$
Order quantity, $q^*$	$az^* \left( \frac{(b - 1)\bar{F}(z^*)}{b(c_m + t)} \right)^b$	$az^* \left( \frac{(b - 1)^2\bar{F}(z^*)}{b^2(c_m + c_l)} \right)^b$	$az^* \left( \frac{(b - 1 + \theta)\bar{F}(z^*)}{b(c_m + c_l)} \right)^b$

**Corollary 6.** In the coordinated supply chain system:

- (i)  $\Pi_m^C(\theta)$  is decreasing in  $\theta$ ;
- (ii) When  $\theta < \tilde{\theta}$ ,  $c_l < t < t_{up}$ , there exists  $\Pi_m^{C^*}(\theta) > \Pi_m^T(w_T^*) >$

$$\Pi_m^I(w_I^*), \text{ with } \tilde{\theta} + \left[ \frac{(b-1+\theta)(c_m+t)}{(b-1)(c_m+c_l)} \right]^{1-b} = 1.$$

Corollary 6 implies that if it is in a Scenario 2 where 3PL only offers ILPS service, the manufacturer may not be willing to cooperate with 3PL. However, if the manufacturer has an altruistic preference, he will prefer to accept ILPS service offered by 3PL and will obtain more profit than the other two scenarios. Result (i) can be proved by the first order derivative of Eq. (25) and Eq. (27). Result (ii) can be proved by Corollary 2. Thus, when  $c_l < t < t_{up}$ ,  $\theta \in (0, \tilde{\theta})$ , where  $\tilde{\theta}$  can be derived from  $\Pi_m^{C^*}(\tilde{\theta}) = \Pi_m^T(w_T^*)$ , a comparison between the profit of manufacturer in different scenarios.

Overall, the conclusions of Corollaries 5 and 6 suggest that a manufacturer with altruistic preference could incentivize 3PL to enter into a revenue-sharing contract with retailers if the interests of the partners are appropriately valued, thereby inducing the retailers to lower their sales prices. It is important to note that, contrary to the findings in Corollaries 1 and 2 that 3PL procurement services in such a way that  $b/(b - 1) < (c_m + t)/(c_m + c_l)$  to ensure increased profits for supply chain members. Under the coordination mechanism we designed, the overall profits of the supply chain could be increased as long as  $t > c_l$  is satisfactory. Since professional 3PLs tend to provide logistics services at lower operating costs, while manufacturers tend to pay higher logistics outsourcing costs to obtain logistics services due to the higher storage and transportation requirements of healthcare products. In addition, the conditions of 3PLs are also present in most industries in reality, and the findings of Corollaries 5 and 6 could lead to the expansion of 3PL procurement services in more industries.

**7. Numerical study**

In this section, the theorems and corollaries above are verified through numerical examples. Recall that our models are inspired by the popular applications in the healthcare sector, where 3PLs offer integrated logistics and procurement services, relying on their transport expertise and accumulated supply resources to act as supply chain orchestrators. In this supply chain system, the 3PL orders to the manufacturer on behalf of a distributor and charges the retailer a service fee when the commodities are delivered. However, the 3PL provider only undertakes transportation services and charges the manufacturer in the traditional supply chain. We consider specific healthcare products such as over-the-counter medicines and self-funded vaccines, which are price sensitive in common. In particular, we suppose that the random variable  $\epsilon$  of the stochastic market demand is distributed following a uniform distribution:  $\epsilon \sim U[0.5, 2]$ . To illustrate the three models discussed in the earlier sections, the following parameter-values are given: the scale of the market demand  $a = 100000$ , the manufacturer's unit production

cost  $c_m = \$5/unit$ , and the 3PL provider's unit operation cost  $c_l = \$1/unit$ . We mainly analyze the impact of price sensitivity, logistics outsourcing cost and manufacturer's altruistic preference on supply chain members' decisions and profits.

**7.1. Comparison and analysis**

The condition where ILPS can prompt the retailer to reduce selling price to stimulate market demand is shown in Fig. 4. The above corollaries imply that ILPS can reduce the retail price only if the supply chain faces a high price-sensitive market demand and the manufacturer faces high logistics outsourcing costs.

However, as shown in Fig. 5, even if the retailer reduces the price when  $\frac{b}{b-1} < \frac{c_m+t}{c_m+c_l}$ , the emergence of the 3PL provider would cause triple marginalization, resulting in that the retailer's and the manufacturer's profits do not necessarily increase at  $\frac{b}{b-1} = \frac{c_m+t}{c_m+c_l}$ . For the given large enough price sensitivity, whether ILPS can further increase the members' profits depends on the manufacturer's logistics outsourcing costs.

**7.2. Impact of logistics outsourcing cost  $t$**

We first give the price sensitivity  $b = 2.5$ . Following the theorems outlined, each participant's optimal operational strategies and the relative profits in Scenario 1 and 2 are obtained as given in Tables 3 and 4, respectively. We pay attention to the effect on the results brought by the varied  $t$ .

Fig. 6 illustrates that the selling price increases with  $t$  while the manufacturer's profit is just the opposite, in Scenario 1. When the manufacturer's logistics outsourcing cost satisfies  $t < t_{low} = 5.00^*$ , the selling price in Scenario 1 is lower than that in Scenario 2. However, for the reason that  $p_T^*$  increases with  $t$ , and  $p_I^*$  keeps stable, these two prices do not archive equal until  $t = t_{low} = 5.00^*$ . In the meantime, although the manufacturer's profit  $\Pi_m^{T^*}$  decreases with  $t$ , it always outperforms  $\Pi_m^{I^*}$ .

The above shows that the high logistics outsourcing cost leads to the finally inflated selling price and the manufacturer's profit loss. Furthermore, at that time  $t_{low} < t < t_{up} = 9.05^*$ , although the manufacturer solves the issue that the high logistics outsourcing cost drives the excessive retail price through ILPS offered by the 3PL provider, the manufacturer's profit  $\Pi_m^{T^*}$  is still greater than  $\Pi_m^{I^*}$ , indicating that the manufacturer should continue to trade with retailers directly. Only when  $t$  is sufficiently large, ILPS would achieve the manufacturer's goal to control the final price and ensure its profit exceeding the traditional level. In other words, although the new business model ILPS has certain advantages, prerequisites are required in the sector of healthcare supply chain management for its promotion. For this reason, we next explore the supply chain performance when the manufacturer has altruistic preference. It is analyzed whether the 3PL provider sharing revenue with the retailer achieves improvements so that ILPS can be more widely applied.

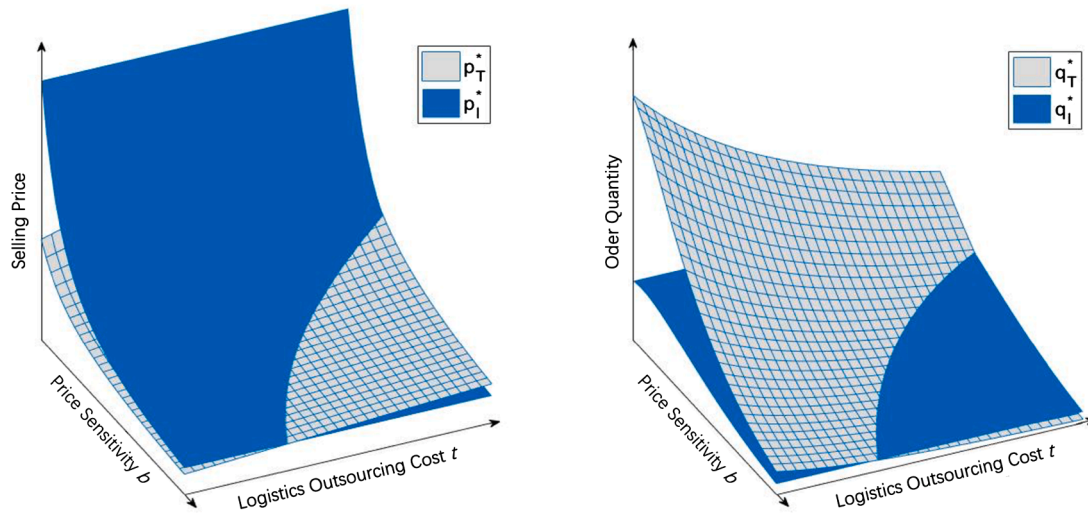


Fig. 4. The varying decisions of the retailer according to  $b$  and  $t$ .

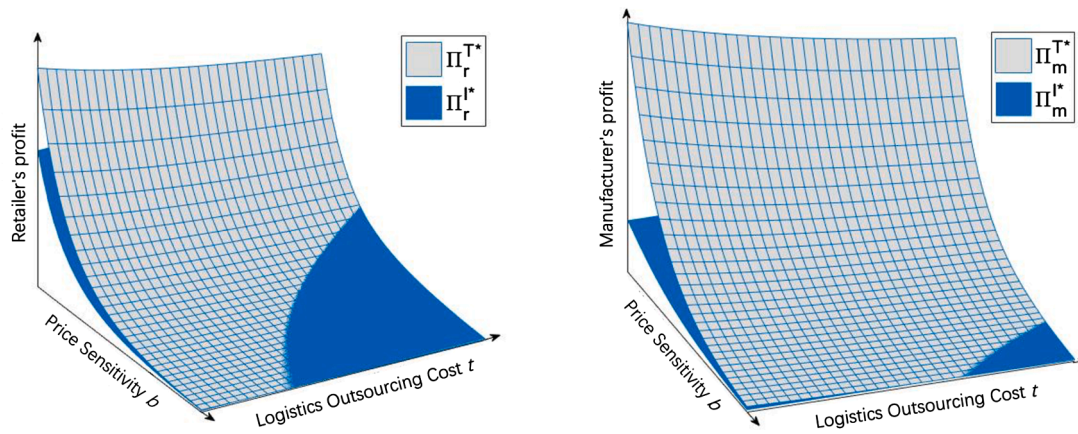


Fig. 5. The varying profits of the retailer and the manufacturer according to  $b$  and  $t$ .

**Table 3**  
Decisions and profits of the supply chain in Scenario 1 with varied  $t$ .

$t$	$z^*$	$p_T^*$	$q_T^*$	$w_T^*$	$\Pi_r^*$	$\Pi_m^*$
1.00	1.23	19.48	73.44	10.00	489.61	293.76
2.00	1.23	22.73	49.95	11.67	388.53	233.12
3.00	1.23	25.97	35.78	13.33	318.01	190.81
4.00	1.23	29.22	26.65	15.00	266.51	159.90
<b>5.00*</b>	<b>1.23</b>	<b>32.47</b>	<b>20.48</b>	<b>16.67</b>	<b>227.55</b>	<b>136.53</b>
6.00	1.23	35.71	16.14	18.33	197.24	118.34
7.00	1.23	38.96	12.98	20.00	173.10	103.86
8.00	1.23	42.21	10.63	21.67	153.52	92.11
<b>9.05*</b>	<b>1.23</b>	<b>45.61</b>	<b>8.75</b>	<b>23.42</b>	<b>136.63</b>	<b>81.98</b>
10.00	1.23	48.70	7.43	25.00	123.86	74.32

**Table 4**  
Decisions and profits of the supply chain in Scenario 2.

$z^*$	$p_T^*$	$q_T^*$	$s_i^*$	$w_T^*$	$\Pi_r^*$	$\Pi_i^*$	$\Pi_m^*$
1.23	32.47	20.48	16.67	9.00	227.55	136.53	81.92

7.3. Impact of altruistic preference  $\theta$

When the 3PL provider commits to use the RS contract with the retailer, the manufacturer also offers the 3PL a lower wholesale price. Table 5 lists the supply chain members' optimal decisions and profits when  $\theta$  changes in the interval  $[0, 1]$ .

When the 3PL shares revenue with the retailer in providing procurement services, regardless of the price sensitivity level, the retailer's optimal price decreases with the altruistic preference  $\theta$  and the order quantity is just the opposite (see Fig. 7).

The retailer reduces the selling price under the RS contract because the manufacturer provides a lower wholesale price for the 3PL provider as the altruistic preference increases (see Fig. 8). This also leads to the manufacturer's profit decrease with  $\theta$ . It is indicated that there is an upper limit  $\tilde{\theta}$  depending on the importance the manufacturer attaches to its partner's profit. Furthermore, regardless of the logistics outsourcing cost, as long as  $\theta < \tilde{\theta}$ , ILPS in a coordinated system is able to prompt the retailer to reduce the selling price and promise a higher profit for the manufacturer.

However, a further look at Fig. 8 shows that even if the manufacturer bears the logistics outsourcing cost  $t = 3.0$  in a direct transaction, as long as the manufacturer's altruistic preference coefficient  $\theta < \tilde{\theta} = 0.61$ , the 3PL's revenue sharing with the retailer could induce it to reduce its sales price, and the manufacturer's profit  $\Pi_m^C(\theta)$  under the

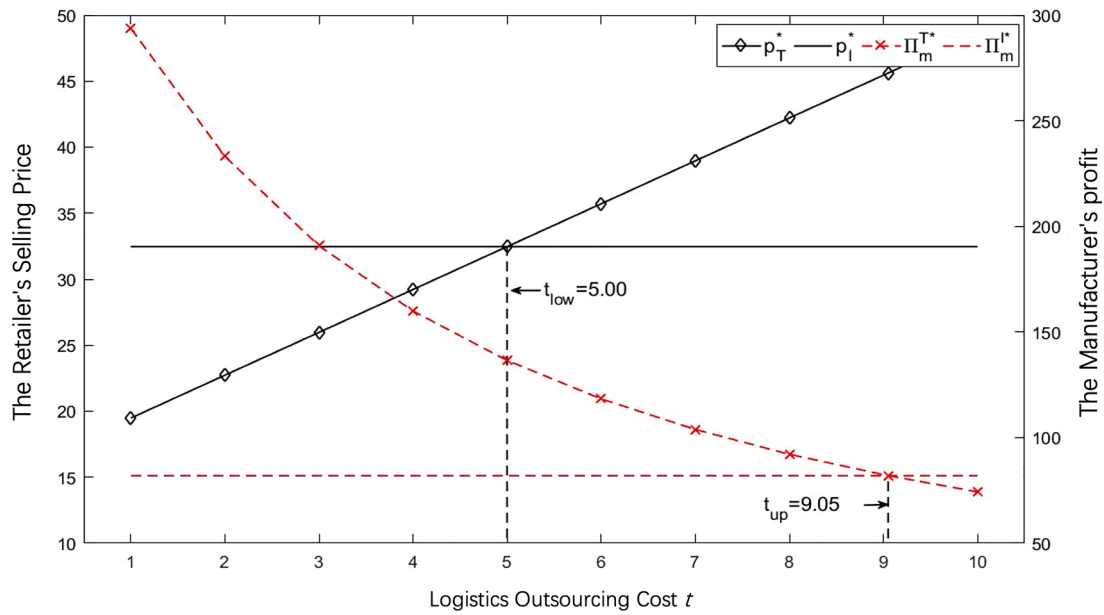


Fig. 6. Impact of  $t$  on selling price and the manufacturer's profit.

**Table 5**  
Decisions and profits of the supply chain in Scenario 3 with varied  $\theta$ .

$\theta$	$z^*$	$p_c^*$	$q_c^*$	$w_c^*$	$\Pi_{sum}^{C^*}$	$\Pi_m^{C^*}$
0.10	1.23	18.26	86.30	8.38	539.37	291.26
0.20	1.23	17.19	100.42	7.82	590.72	283.55
0.30	1.23	16.23	115.85	7.33	643.60	270.31
0.40	1.23	15.38	132.62	6.89	697.98	251.27
0.50	1.23	14.61	150.76	6.50	753.80	226.14
<b>0.61*</b>	<b>1.23</b>	<b>13.85</b>	<b>172.35</b>	<b>6.11</b>	<b>816.83</b>	<b>191.14</b>
0.70	1.23	13.28	191.32	5.82	869.65	156.54
<b>0.79*</b>	<b>1.23</b>	<b>12.76</b>	<b>211.49</b>	<b>5.55</b>	<b>923.56</b>	<b>116.37</b>
0.90	1.23	12.17	237.81	5.25	990.89	59.45

ILPS (revenue sharing) is larger than its profit under a direct transaction  $\Pi_m^{T^*}(t = 3.0)$ . Similarly, given the logistics outsourcing cost  $t = 6.0$ , the ILPS (revenue sharing) is more beneficial to the manufacturer as long as  $\theta < \hat{\theta} = 0.79$ , there exists  $\Pi_m^{C^*}(\theta) > \Pi_m^{T^*}(t = 6.0)$ .

So far, it can be explained that when the manufacturer with an

altruistic preference encourages the 3PL provider to share revenue with the retailer, even if they are not in a business environment with high price-sensitive demand and great logistics outsourcing cost, the products should also be distributed through the 3PL provider. However, it remains unclear concurrently whether there is a reasonable interval of the profit distribution ratio to increase both players' profits in Scenario 3. This should be further investigated.

#### 7.4. Analysis of the coordination contract

As shown in Fig. 9, no matter how the price sensitivity changes in Scenario 3, the optimal selling price is less than that in Scenario 1. Meanwhile, the optimal quantity is just the opposite. Thus, the RS contract with the altruistic preference could always prompt the retailer to reduce the selling price.

Recall that the larger  $\theta$  is, the lower the wholesale price the 3PL provider confronts. Thus, the total profit of the 3PL and the retailer also increases with  $\theta$ . This eventually leads to a gradual decrease in the minimum profit distribution ratio of the 3PL provider under the RS

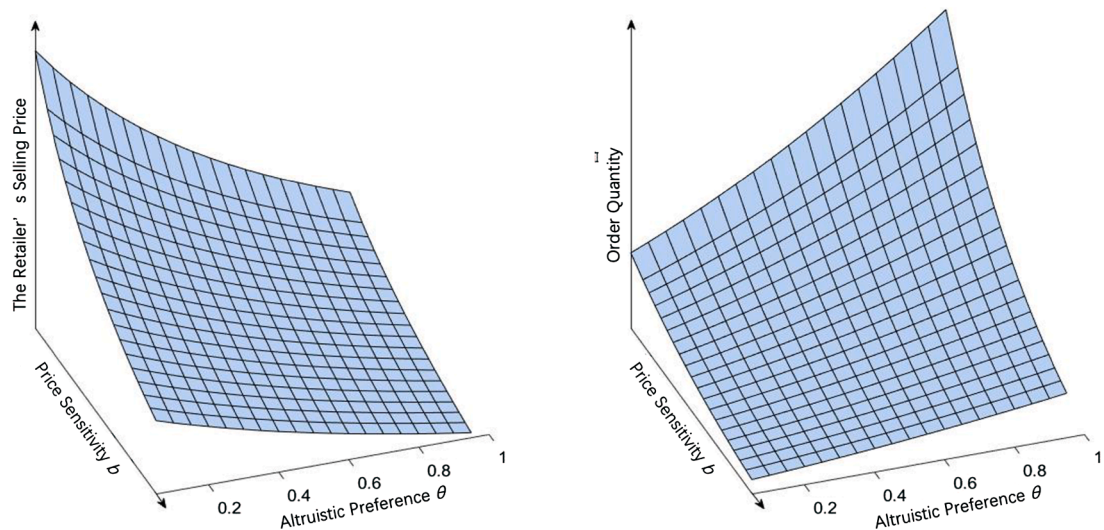


Fig. 7. Impact of  $\theta$  on retailer's decisions in Scenario 3.

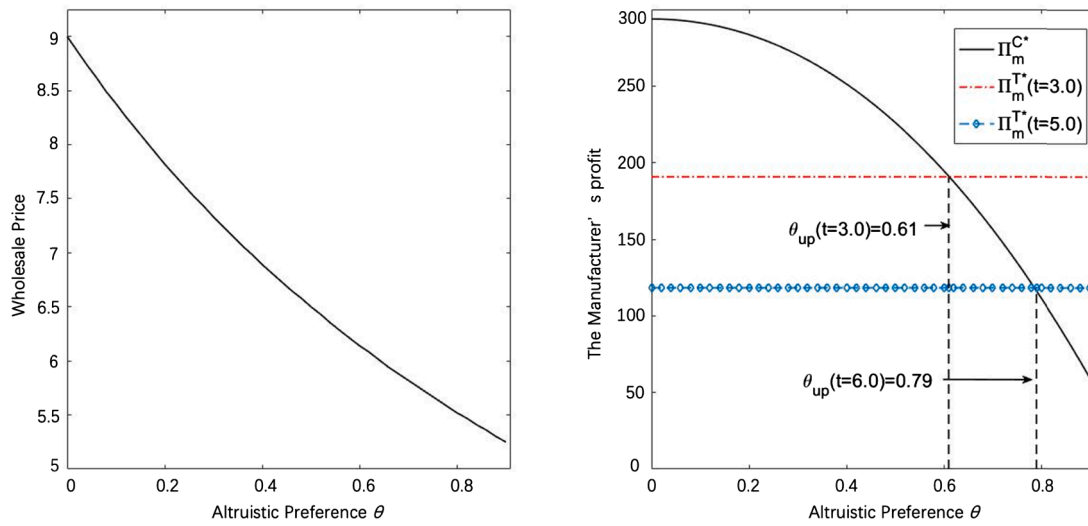


Fig. 8. Impact of  $\theta$  on the manufacturer's wholesale price and profit.

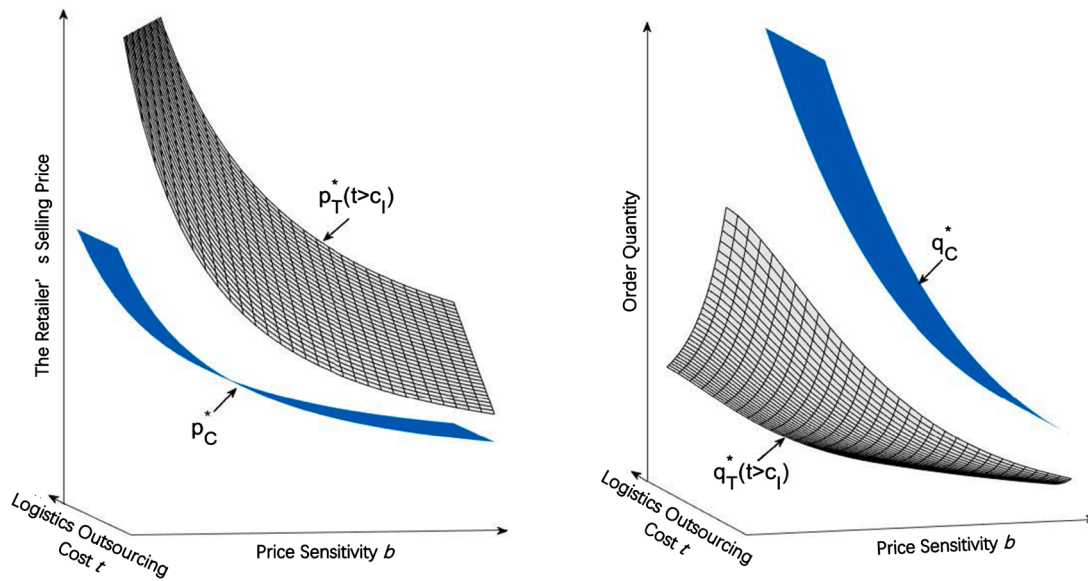


Fig. 9. Comparison of  $p^*$  and  $q^*$  in Scenario 1 and 3

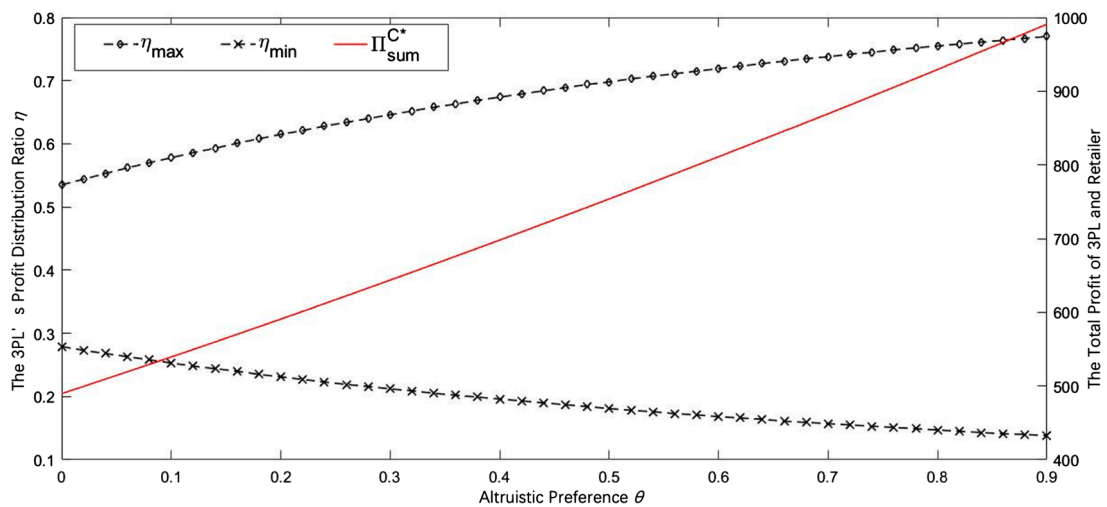


Fig. 10. Influence of  $\theta$  on profit distribution ratio and total profit.

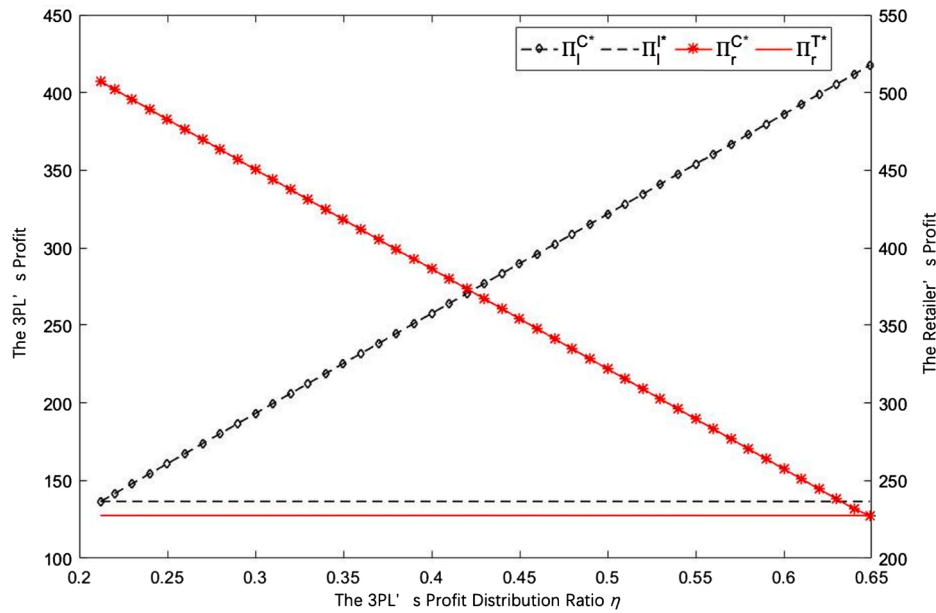


Fig. 11. Profit distribution between the 3PL and the retailer in Scenario 3.

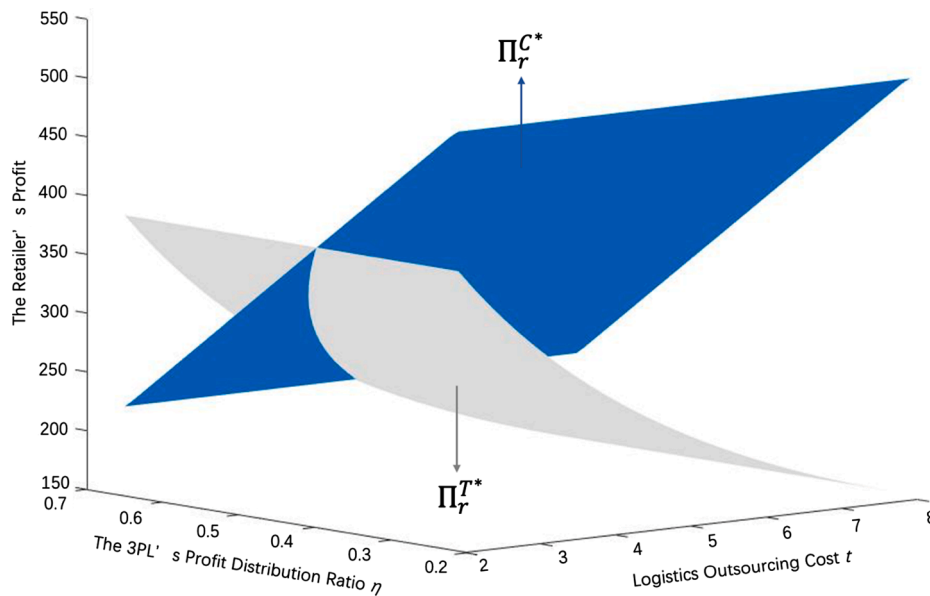


Fig. 12. Comparison of the retailer's profit in Scenario 1 and 3.

contract, while a gradual increase in the maximum profit distribution ratio. Therefore, a more extensive range will exist, where the profits of the 3PL and the retailer are higher than those under decentralized systems (see Fig. 10).

Taken  $\theta = 0.3$  as an example: we can further obtain results reflected in Figs. 11 and 12, which verifies the conclusions above. Fig. 12 also illustrates that  $\Pi_r^{T^*}$  decreases with  $t$  and  $\Pi_r^{C^*}$  decreases with  $\eta$ . Regardless of  $t$ , the 3PL can adjust its profit distribution ratio to satisfy  $\Pi_r^{C^*} > \Pi_r^{T^*}$ .

In summary, the revenue sharing contract with altruistic preference we propose provides a win-win situation as the selling price is maintained at a lower level as the manufacturer expects, and all the participating entities' profits increase concurrently.

### 8. Conclusions

Motivated by the characteristics of a novel role of 3PLs in the

healthcare supply chain, which offer value-added procurement service for retailers, we develop a game-theoretic model of a healthcare supply chain consisting of a manufacturer, a 3PL provider, and a retailer. The equilibrium price and order decisions of *model T* and *model ILPS* are investigated, respectively. We examine the impacts of logistics outsourcing costs and price sensitivity on the equilibrium outcomes for the healthcare supply chain by comparing the results derived from these two models. We give the conditions where *model ILPS* outperforms *model-T* and then design a revenue sharing contract with altruistic preference to coordinate the supply chain.

We sum up the main arguments and contributions of this paper in three aspects:

- (1) Motivated by the novel application of ILPS in real-life healthcare supply chain systems, we establish a generic and creative business model based on the Stackelberg game to address each

participant's optimal operational strategies, including a manufacturer, a 3PL provider, and a retailer. We formulate a multiplicative demand function, where the market size is assumed to be a function of the retail price to capture the sensitivity of the market demand of the specific healthcare product.

- (2) We characterize the optimal wholesale price of the manufacturer, the optimal service price of the 3PL provider (if it exists), and the optimal order quantity and selling price of the retailer in two decentralized supply chains and a coordinated supply chain system (in which each player acts to maximize the joint profit of itself and its partner), respectively. We evaluate these results and gain managerial insights, mainly focusing on the suitable conditions of application of ILPS. We demonstrate that only when market demand is price-sensitive and logistics outsourcing costs are high, ILPS can prompt retailers to reduce their sales price to stimulate market demand, thereby increasing the profits of manufacturers and retailers than in direct transactions.
- (3) We develop an incentive mechanism to facilitate the coordination among the three players, referred to as the revenue sharing contract with altruistic preference. It is shown that the proposed contract allows the supply chain to maintain the selling price at a lower level, and eliminate the possible sources of "triple marginalization" in the decentralized system, thus, allowing ILPS to be applied under more conditions. Considering the reality that 3PL forms a partnership with the manufacturer when providing sourcing services, we find that even though the cost of logistics outsourcing is low, the manufacturer who values the interests of its partners will offer lower wholesale price to 3PL. This can provide an incentive for 3PL to enter into a revenue-sharing contract with the retailer in the healthcare industry, it can also encourage the 3PL to provide ILPS in a wider range of industries. It is also in line with *Eternal Asia's* "Sales Partners" program to develop the ILPS model across industries.

Healthcare supply chains involving the 3PL provider offering value-added services have become increasingly common in markets worldwide, but the investigation of interactions between the 3PL provider and its clients is a relatively new research direction. There are several practical and unresolved issues for further study. One is to extend the ILPS model incorporating information asymmetry caused by private information in practice. Another is that supply chain members have different attitudes towards risks, who are assumed both risk-neutral in this paper as a standard assumption built-in relevant management literature. It is also intriguing to consider the market in a competitive setting or a random yield model of unique healthcare products.

#### CRedit authorship contribution statement

**Wenliang Bian:** Conceptualization, Methodology, Software, Validation, Writing – review & editing. **Xiqing Yang:** Validation, Formal analysis, Writing – original draft. **Shichang Li:** Data curation, Visualization, Investigation. **Xiying Yang:** Validation, Formal analysis, Writing – review & editing. **Guowei Hua:** Supervision, Funding acquisition.

#### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

#### Acknowledgment

This research was supported by the National Natural Science Foundation of China (NSFC) under grant number 71831001.

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