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Research on the improvement mechanism of value-based healthcare objectives in pharmaceutical group procurement

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ABSTRACT

Focusing on the research scenario that integrates value-based healthcare objectives with the pharmaceutical group purchasing model, this study delineates value-based healthcare objectives in pharmaceutical group purchasing from three perspectives: drug sales price, drug quality, and service level. We construct a three-level pharmaceutical group purchasing supply chain consisting of drug manufacturers, medical institutions, and non-profit drug group purchasing organisations. Under centralised and decentralised decision-making, we introduce cost-sharing contracts and "cost-sharing-quantity-discount" contracts to analyse the impact of factors such as drug sales price, quality, and sensitivity of the service level. The study found that: (1) Compared with centralised decision-making, the optimal drug quality and service level in decentralised decision-making and the optimal profits of drug manufacturers and medical institutions will decrease. However, the optimal drug sales price in decentralised decision-making always deviates from that in centralised decision-making, leading to higher or lower drug sales prices. (2) The incorporation of value-based healthcare objectives in the pharmaceutical group purchasing through cost-sharing contracts depends on changes in the proportion of drug quality costs borne by medical institutions. If the proportion is too high, medical institutions will suffer greater losses because they bear too much of the cost. (3) Under certain conditions, cost-sharing contracts can improve supply chain efficiency but cannot achieve supply chain coordination, while the combination of "cost-sharing-quantity-discount" contracts can achieve supply chain coordination in pharmaceutical group purchasing.

1. Introduction

Michael Porter, the father of strategic management, first proposed the concept of value-based healthcare in 2006. He emphasised the maximisation of medical quality and effectiveness using even lower costs [1]. This concept played an important role in improving the governance of medical reform in developed countries; for example, the United States implemented value-oriented medical service purchase projects to fully mobilise the enthusiasm of hospitals, guide the improvement of medical behaviour, and constantly promote the improvement of medical quality [2]. In 2016, the Chinese government, along with the World Bank and World Health Organization, jointly released a medical reform report titled "Deepening the Reform of the Chinese Health-care System — Building a High-quality Service Delivery System Based on Value" [3]. This marked the official introduction of value-based healthcare in China, which became an important future development trend in the country's healthcare reform [4–6]. As an important part of medical reform, drug

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procurement must also follow the concept of value-based healthcare. A group purchasing organisation (GPO) helps improve purchasing efficiency and reduces purchasing costs by pooling the purchasing volume of its member agencies and utilising its negotiating power [7]. In the context of pharmaceuticals, a pharmaceutical group purchasing organisation is a branch of a GPO specifically focused on the pharmaceutical sector. It is a specialised third-party institution introduced into the traditional pharmaceutical supply chain. The pharmaceutical GPO integrates the medication demands of medical institutions, negotiates prices with pharmaceutical manufacturers, and provides high-quality drug procurement services to medical institutions. It is an effective approach employed by developed countries to control drug procurement costs, ensure pharmaceutical supply efficiency, and prevent drug shortages [8]. Unlike GPO models in other developed countries, China has conducted a localised exploration of GPO models based on its own national conditions. The non-profit GPO is a model promoted by the government that is more suitable for China's drug market. This approach has achieved remarkable results in reducing drug prices and the burden of drug costs, providing diversified service functions, and promoting the development of drug GPO in China. In 2016, Shanghai took lead in the pilot pharmaceutical group purchasing and became a pioneer in domestic pharmaceutical procurement reform. The Shanghai Medical and Health Affairs Services Centre took the responsibilities of the GPO, acting as a third-party non-profit organisation under the guidance of the Shanghai Health Reform Office [9]. Pharmaceutical group procurement might play an important role in coordinated development with national centralised drug purchasing [10,11], and practising value-based healthcare might become an essential requirement for the future development of drug group purchasing.

The concept of value-based healthcare has been proposed for less than 20 years, whereas the group purchasing of drugs has a history of more than 100 years in developed countries. Drug group purchasing has not effectively realised the vision of value-based healthcare while controlling medical costs. One of the main reasons for this is that, under high investment, the improvement of the drug GPO has fallen behind, resulting in low output. Domestic drug group purchases began relatively late, and were limited by the development of the Chinese drug market. The drug group purchasing organisation did not perform well in diversified services and values, such as drug supply chain management, big data application, and drug demand forecasting, bringing considerable room for improvement to the value-based healthcare goals in drug group purchasing. Simultaneously, members of the drug supply chain often pursue the maximisation of their own interests, resulting in a decrease in the overall profit of the supply chain and an increase in costs, exacerbating the double marginal effects of the supply chain. Therefore, whether GPO can transit from "price-oriented" to "value-oriented" and ensure that patients can obtain reliable and effective drugs at an affordable price is a pressing issue that needs to be addressed in the era of value-based healthcare, and it is also an important standard for measuring the value-based healthcare level of drug group purchasing.

Drug group purchasing is a cost control method widely used in developed countries that integrates the drug demand of medical institutions through group purchasing organisations, negotiates prices with drug manufacturers, and provides high-quality drug procurement services for medical institutions. While drug GPO can obtain lower drug prices by signing quantity discount contracts with drug manufacturers through large-scale procurement methods, and can reduce purchasing costs and improve procurement efficiency through specialised procurement techniques; the drug group purchasing supply chain can also establish a cost-sharing mechanism and cooperative relationships among members. It can take on certain drug quality or service risks, and improve drug quality and service levels by sharing costs among different roles in the supply chain. Some researchers have also shown that contracts can be effective in reducing drug prices or improving drug quality, but there is little literature on improving the value-based healthcare goals in drug group purchasing [12,13]. Therefore, the question of how to promote the effective functioning of the drug group purchasing supply chain and improve the level of value-based healthcare through contract coordination mechanisms has been an important issue in recent years.

Therefore, this study adopts game theory to design a more effective coordination mechanism. The focus is on proposing and answering two questions: (1) How can we better characterise the value of medical goals in pharmaceutical group procurement? (2) Can the cost-sharing contract and the cost-sharing quantity discount contract play an improving role around the value of medical goals in pharmaceutical group procurement, and thus form a sustainable coordination mechanism? Compared to previous research, this study is grounded in the management practices of value-based healthcare and pharmaceutical group purchasing in China. We have constructed a three-tier supply chain model consisting of pharmaceutical manufacturers, non-profit GPOs, and medical institutions. We depicted the value-based healthcare goals in pharmaceutical group purchasing and identified the feasible conditions for the "cost-sharing–quantity-discount" contract to play a role. This study provides a theoretical basis and governance recommendations to promote value-based healthcare in pharmaceutical group purchases. It aims to help reduce drug prices, improve drug quality, and enhance service levels. In addition, it advocates the implementation of pharmaceutical group-purchasing models based on value-based healthcare.

2. Literature review

2.1. Value-based healthcare goals

Professor Michael Porter pointed out that value-based healthcare aims to maximise healthcare quality or outcomes achieved at the same or lower cost [1], in response to problems in the US healthcare system. Scholars abroad believe that the core of value-based healthcare is the relationship between healthcare costs and patient outcomes [14]. Ever since value-based healthcare was introduced in China in 2016, research on this topic has gradually expanded. In 2017, the China Value-based Healthcare Summit proposed the "Value-based Healthcare 5E Framework": improve efficacy, enhance efficiency, enhance effectiveness, empower patients, and promote empathy. It emphasises that value-based healthcare advocates a balance of interests between the supply side (suppliers and medical institutions) and the demand side (patients). Following Michael Porter's concept of value-based healthcare and drawing on the

core ideas of the Chinese version of the "Value-based Healthcare 5E Framework", value-based healthcare centres on patients and achieves the best treatment effect at the same or lower cost [15], by balancing and optimising healthcare quality, patient experience, and cost standards [4]. Therefore, based on the views of the above scholars, this study characterizes the value-based healthcare goals in pharmaceutical group procurement from three aspects: drug sales price, drug quality, and drug service level.

2.2. Group purchasing of pharmaceuticals

Group purchasing is an important model for modern procurement management. This involves an independent third-party group purchasing organisation (GPO) that integrates the dispersed buying power of downstream buyers to negotiate prices with upstream sellers, thereby reducing procurement prices [7]. The theoretical community has extensively discussed how group purchases can reduce procurement prices. In addition to the basic viewpoint that group purchasing can achieve economies of scale [16], there are other ways to lower prices. Group purchases promote competition among suppliers [17]. Enterprises involved in group purchasing have stronger bargaining power [18,19]. A differential pricing model, in which upstream suppliers provide price discounts to the GPO, can reduce the degree of tacit collusion among purchasing enterprises [20]. Most existing studies model general group purchasing organisations. However, in recent years, an increasing amount of research has been conducted on GPOs in the pharmaceutical industry. Hu et al. first established a game theory model for GPOs in the pharmaceutical industry by studying the impact of GPOs on the supply chain of medical products and found that GPOs can reduce procurement costs for supply chain members [21,22]. Group purchasing in the pharmaceutical industry originated in the United States, and is currently an effective way to control procurement costs in most developed countries. This is a typical example of market-oriented operations in pharmaceutical procurement. However, the characteristics of pharmaceutical group-purchasing organisations vary from country to country [23]. Currently, there is scant research on characteristics, including drug prices, drug quality, and patient medication experience in pharmaceutical group purchases. Therefore, this study combines the localised characteristics of pharmaceutical procurement in China to explore the value-based healthcare objectives in pharmaceutical group purchasing, which is of practical significance.

2.3. Coordination of pharmaceutical supply chain contracts

The coordination function of the supply chain serves as a link between upstream and downstream companies to enhance the coordination ability in the supply chain environment, and a reasonable application of coordination theory can optimise supply chain problems under decentralised decision-making [24]. Most scholars have found that contracts are an effective way to achieve supply chain coordination. The contract coordination problem in pharmaceutical supply chain has drawn widespread attention from the academic community. Some scholars have proposed that through contract coordination strategies, cooperation among pharmaceutical supply chain members can be optimised, and the innovative research and development motivation of pharmaceutical supply chain members can be effectively stimulated, increasing the overall benefits of the pharmaceutical supply chain [25–28]. Therefore, many scholars have studied contract theory to solve the coordination problem in the pharmaceutical supply chain. Johari et al. studied competitive drug supply chain coordination contracts considering corporate social responsibility and pricing decisions [29]. Pu et al. considered the impact of free-riding behaviour on a dual-channel pharmaceutical supply chain using a cost-sharing contract to coordinate the profit distribution of online and offline pharmaceutical retailers and found that the contract can improve the efficiency of the supply chain under random demand [30]. Some scholars have also introduced group purchasing organisations into the pharmaceutical supply chain to study their cooperation and incentive problems. Guo et al. analysed the optimal pricing decision problem of a competitive drug supply chain and explored the coordination mechanism of the pharmaceutical group purchasing supply chain system with non-symmetrical drug retailers of different scales [31]. Overall, the literature on contract coordination among pharmaceutical groups' purchasing supply chains is relatively fragmented. Further exploration can be conducted by integrating this with the Chinese context of localisation.

This subject was searched in databases such as Web of Science and CNKI (China National Knowledge Infrastructure). A total of 3257 and 671 articles were retrieved on the topic of "value-based healthcare" and "group purchasing of pharmaceuticals", respectively. Important research situations in related fields are shown in Tables 1 and 2.

Through a literature review, it was found that value medicine is widely used in the field of medicine and health care, but relatively few studies have applied the concept of value medicine to the field of pharmaceutical supply chain, and few have paid attention to the purchasing mode of pharmaceutical groups. Therefore, this study organically integrates value medicine and drug group procurement, explores the effective coordination of the drug group procurement supply chain under the guidance of value medicine, and provides a

Table 1
Important research situation in the field of value-based healthcare.

Field	value-based healthcare
Representative literature	Patient Satisfaction and Quality of Surgical Care in US Hospitals The Role of Patient-Reported Outcome Measures in Value-Based Payment Reform Current State of Value-Based Purchasing Programs A Health Economics Approach to US Value Assessment Frameworks—Introduction: An ISPOR Special Task Force Report Advanced therapy medicinal products and health technology assessment principles and practices for value-based and sustainable healthcare
Number of articles	3257

Table 2
Important research situation in the field of group purchasing of pharmaceuticals.

Field	group purchasing of pharmaceuticals
Representative literature	Controversial role of GPOs in healthcare-product supply chains Mitigating the US Drug Shortages Through Pareto-Improving Contracts Centralised Pharmaceutical Procurement: Learnings from Six European Countries A Systematic Review of Pooled Procurement of Medicines and Vaccines: Identifying Elements of Success The impact of group purchasing organisations on healthcare-product supply chains
Number of articles	671

reference for subsequent research.

3. Problem description

The GPO integrates the drug demand. Professional procurement technologies can reduce procurement costs and play an important role in reducing drug prices. Pharmaceutical manufacturers are significant contributors to drug quality and safety. They can provide patients with higher-quality and safer drugs through various measures such as the production of high-quality drugs and strict quality control. Medical institutions are the important providers of drug services. They can play a role in optimising drug service processes, expanding the scope of drug services, and providing patients with higher quality and more reliable drug services. However, these three main entities can only improve the quality and efficacy of drugs and provide patients with the best quality and most economical drug treatment services through cooperation and coordination.

Based on the above description, this study considers a three-tiered supply chain structure composed of pharmaceutical manufacturers, non-profit GPOs, and medical institutions. It matches the value-based medical goals with the three main entities of pharmaceutical group purchasing. The research framework is shown in Fig. 1.

3.1. Basic assumptions

(1) Based on the above description, this study adopts the market demand function $Q = q - lp + \theta\beta + \gamma g$ [32], which has been used by many scholars. Market demand is determined by sales price, quality, and service levels of pharmaceuticals. In other words, demand for pharmaceuticals decreases with an increase in sales price and increases with an increase in quality and service level.
(2) Considering the localisation feature of pharmaceutical procurement in China, the group purchases pharmaceuticals and sells them according to the "zero markup" policy. Medical institutions sell pharmaceuticals to patients at purchase prices without markups. To reflect the real background, this study assumes that the pharmaceutical sales price decided by medical institutions includes both wholesale and service prices of pharmaceuticals.
(3) Assuming that the cost of pharmaceutical quality and the level of pharmaceutical quality are in a quadratic relationship, and the cost of pharmaceutical service and the level of pharmaceutical service are in a quadratic relationship, that is, the product quality cost is $k_1\beta^2$, and the after-sales service cost is k_2g^2. If k_1 and k_2 are higher, they represent higher coefficients of pharmaceutical quality cost and service cost, respectively, indicating higher costs for improving pharmaceutical quality and service level. In the pharmaceutical group procurement supply chain, the pharmaceutical manufacturing enterprise decides the pharmaceutical wholesale price w and the pharmaceutical quality level β, and bears the quality cost $k_1\beta^2$; the medical institution decides the pharmaceutical sales price p and the pharmaceutical service level g, and bears the service cost k_2g^2 [33,34]; the non-profit GPO decides the contract management fee rate δ.
(4) Considering the positive benefits of pharmaceutical manufacturers and healthcare institutions, we assume that $p > w > c$ and the unit production cost of pharmaceutical manufacturing enterprises are negligible.

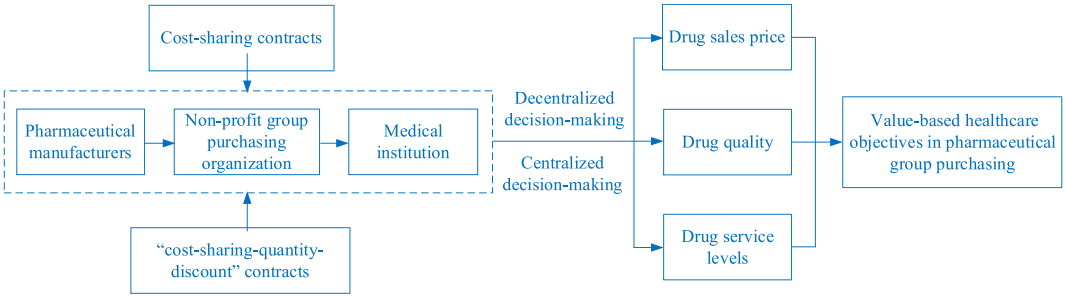

Fig. 1. Research framework.

3.2. Symbol description

Symbol	Explanation
w	Wholesale price of drugs produced by pharmaceutical manufacturers
p	Sales price of drugs for medical institutions
β	Quality of drugs produced by pharmaceutical manufacturers
g	Service level of drug provision provided by healthcare institutions to patients
q	Scale of the pharmaceutical market
c	Unit drug procurement cost for a non-profit Group Purchasing Organization (GPO)
δ	Contract management fee rate
l	Factors that affect patient sensitivity to drug prices
θ	Factors that affect patient sensitivity to drug quality
γ	Factors that affect patient sensitivity to the level of pharmaceutical services
k_1	The cost coefficient that pharmaceutical manufacturers have invested to improve the quality of pharmaceutical products
k_2	The cost coefficient that medical institutions have invested to improve the quality of pharmaceutical services
t	The proportion of quality costs that medical institutions share with pharmaceutical manufacturers
d	The discount rate based on the quantity of drugs ordered

4. Model building and analysis

4.1. Decentralised decision-making

Under decentralised decision-making, pharmaceutical manufacturers and medical institutions aim to maximise their own profits, whereas non-profit GPOs reduce the purchasing costs of the supply chain through specialised procurement techniques and cover their own drug procurement costs by charging contract management fees from pharmaceutical manufacturers. This allows them to achieve a balance between revenues and expenses [35]. Pharmaceutical manufacturers bear the cost of drug quality; medical institutions bear the cost of drug services. This study utilises the reverse induction method to seek optimal decision-making. Non-profit GPOs act as leaders in the drug group purchasing supply chain, whereas pharmaceutical manufacturers and medical institutions serve as followers in the supply chain. At this point, the profit functions of the pharmaceutical manufacturers, non-profit GPOs, and medical institutions are respectively determined as Equations (1)–(3).

$$\pi_1 = w(1-\delta)(q - lp + \theta\beta + \gamma g) - k_1\beta^2 \tag{1}$$

$$\pi_2 = (w\delta - c)(q - lp + \theta\beta + \gamma g) \tag{2}$$

$$\pi_3 = (p - w)(q - lp + \theta\beta + \gamma g) - k_2 g^2 \tag{3}$$

Proposition 1. By solving the system of equations composed of $\frac{\partial\pi_1}{\partial w} = 0$, $\frac{\partial\pi_1}{\partial\beta} = 0$, $\pi_2 = 0$, $\frac{\partial\pi_3}{\partial p} = 0$, and $\frac{\partial\pi_3}{\partial g} = 0$, we can obtain the optimal wholesale price, quality, sales price, service level, and contract management fee rate for drugs under decentralised decision-making as Equations (4)–(8).

$$w^{D*} = \frac{4k_1k_2lq - k_1q\gamma^2 - ck_2l\theta^2}{l\left(8k_1k_2l - 2k_1\gamma^2 - k_2\theta^2\right)} \tag{4}$$

$$\beta^{D*} = \frac{k_2\theta(q - 2cl)}{8k_1k_2l - 2k_1\gamma^2 - k_2\theta^2} \tag{5}$$

$$p^{D*} = \frac{(6k_2l - \gamma^2)\left(4k_1k_2ql - k_1q\gamma^2 - ck_2l\theta^2\right)}{l(4k_2l - \gamma^2)\left(8k_1k_2l - 2k_1\gamma^2 - k_2\theta^2\right)} \tag{6}$$

$$g^{D*} = \frac{\gamma\left(4k_1k_2ql - k_1q\gamma^2 - ck_2l\theta^2\right)}{(4k_2l - \gamma^2)\left(8k_1k_2l - 2k_1\gamma^2 - k_2\theta^2\right)} \tag{7}$$

$$\delta^{D*} = \frac{cl\left(8k_1k_2l - 2k_1\gamma^2 - k_2\theta^2\right)}{4k_1k_2ql - k_1q\gamma^2 - ck_2l\theta^2} \tag{8}$$

Therefore, we can obtain the profits of pharmaceutical manufacturers and medical institutions under decentralised decision-making as Equations (9) and (10) respectively.

$${\pi_1}^{D*} = \frac{k_1k_2q(q - 2cl)}{8k_1k_2l - 2k_1\gamma^2 - k_2\theta^2} \tag{9}$$

$$\pi_3^{D*} = \frac{k_2\left(4k_1k_2ql - k_1q\gamma^2 - ck_2l\theta^2\right)^2}{(4k_2l - \gamma^2)\left(8k_1k_2l - 2k_1\gamma^2 - k_2\theta^2\right)^2} \tag{10}$$

To ensure the meaningfulness of the problem and guarantee that the decision given by the model is positive, the above parameters should satisfy the following conditions: $q - 2cl > 0$ and $4k_2l - \gamma^2 > 0$。

According to Proposition 1, the following inference can be further drawn:

Inference **1:** (1) w^{D*}, β^{D*}, p^{D*}, g^{D*}, π_1^{D*}, π_3^{D*} decrease with the increase of l, and δ^{D*} increases with the increase of l.

(2) w^{D*}, β^{D*}, p^{D*}, g^{D*}, π_1^{D*}, π_3^{D*} increase with the increase of θ, and δ^{D*} decreases with the increase of θ.

(3) w^{D*}, β^{D*}, p^{D*}, g^{D*}, π_1^{D*}, π_3^{D*} increase with the increase of γ, and δ^{D*} decreases with the increase of γ.

Inference 1 suggests that under a decentralised decision-making mode, the optimal prices, quality, and service levels of drugs as well as the optimal profits of drug manufacturers and medical institutions are positively correlated with the sensitivity factors of drug quality and service levels. However, they are negatively correlated with the sensitivity factor of the drug sales price. Increasing sensitivity to factors related to the quality of medicines or the level of service provided will simultaneously increase efforts by pharmaceutical companies to improve the quality of their products and healthcare institutions to improve the level of service provided to patients. Healthcare institutions are willing to improve their service levels, whereas pharmaceutical companies are willing to improve their product quality and make efforts towards this goal. Subsequently, pharmaceutical companies and healthcare institutions balance the cost of improvements in quality and service levels by raising wholesale and retail prices, which ensures an increase in their profits. While patients may purchase medicines at a higher price, they will receive higher-quality medicines and better service, resulting in an enhanced perceived value of medicinal products in terms of both quality and service, and increasing overall patient welfare. However, the optimal contract management fee rate of the non-profit GPO is positively correlated with the drug sales price sensitivity factor and negatively correlated with the drug quality and service level sensitivity factor. This is because when the drug quality and service level sensitivity factors increase, the non-profit GPO will reduce contract management fees, thereby encouraging drug manufacturers and medical institutions to actively improve drug quality and service levels.

4.2. Centralized decision-making

Under centralised decision-making, the entire supply chain operates with the goal of maximising profits while making decisions on drug sales prices, drug quality, and drug service levels. The total profit under centralised decision-making as Equation (11).

$$\pi = (p - c)(q - lp + \theta\beta + \gamma g) - k_1\beta^2 - k_2g^2 \tag{11}$$

Proposition 2. *Under centralized decision-making, when the following conditions are met:* $4lk_1k_2 - k_1r^2 - k_2\theta^2 > 0$, *there exist optimal drug sales prices, drug quality levels, and drug service levels that maximize the total profit of the supply chain.*

Proof: the Hessian matrix of π with respect to p, β, and g is:

$$H = \begin{bmatrix} -2l & \theta & \gamma \\ \theta & -2k_1 & 0 \\ \gamma & 0 & -2k_2 \end{bmatrix}$$

According to Equation (11), the first-order principal minor $-2l < 0$ is negatively definite when the second-order principal minor $4k_1l - \theta^2 > 0$ and the third-order principal minor $4k_1k_2l - k_1\gamma^2 - k_2\theta^2 > 0$ are satisfied, indicating that the profit function is a jointly concave function with respect to p, β, and g, and there exists a unique optimal solution that maximises the total profit. When the third-order principal minority is satisfied, the second-order principal minority $4lk_1 - \theta^2 > 0$ is also satisfied; therefore, $4k_1k_2l - k_1\gamma^2 - k_2\theta^2 > 0$. By setting the first-order partial derivatives of the total profit of the supply chain with respect to p, β, and g to zero, the optimal drug sales price, quality, and service level under centralised decision-making can be obtained as Equations (12)–(14) respectively.

$$p^{C*} = \frac{2k_1k_2q + 2ck_1k_2l - ck_1\gamma^2 - ck_2\theta^2}{4k_1k_2l - k_1\gamma^2 - k_2\theta^2} \tag{12}$$

$$\beta^{C*} = \frac{k_2\theta(q - cl)}{4k_1k_2l - k_1\gamma^2 - k_2\theta^2} \tag{13}$$

$$g^{C*} = \frac{k_1\gamma(q - cl)}{4k_1k_2l - k_1\gamma^2 - k_2\theta^2} \tag{14}$$

By substituting Equations (12)–(14) into the total profit function of the supply chain in Equation (11), we obtain the optimal profit of the supply chain under centralised decision-making as Equation (15).

$$\pi^{C*} = \frac{k_1k_2(q - cl)^2}{4k_1k_2l - k_1\gamma^2 - k_2\theta^2} \tag{15}$$

To ensure the meaningfulness of the problem and that the decisions given by the model in the study are positive, the above

parameters should satisfy the following conditions: $q - cl > 0$, $4k_1k_2l - k_1\gamma^2 - k_2\theta^2 > 0$, $2k_1k_2q + 2ck_1k_2l - ck_1\gamma^2 - ck_2\theta^2 > 0$。

4.3. Comparative analysis of the model

By comparing the optimal decisions under the different models, the following conclusions can be drawn:

Inference **2:** (1) The optimal quality level of drugs

$$\beta^{C*} = \frac{k_2\theta(q-cl)}{4k_1k_2l - k_1\gamma^2 - k_2\theta^2} > \frac{k_2\theta(q-2cl)}{8k_1k_2l - 2k_1\gamma^2 - k_2\theta^2} = \beta^{D*}$$

(2) The optimal level of drug services

$$g^{C*} = \frac{k_1\gamma(q-cl)}{4k_1k_2l - k_1\gamma^2 - k_2\theta^2} > \frac{\gamma\left(4k_1k_2ql - k_1q\gamma^2 - ck_2l\theta^2\right)}{\left(4k_2l - \gamma^2\right)\left(8k_1k_2l - 2k_1\gamma^2 - k_2\theta^2\right)} = g^{D*}$$

(3) Total supply chain profits

$$\pi^{C*} > {\pi_1}^{D*} + {\pi_3}^{D*}$$

Inference 2 states that, compared to centralised decision-making, both drug production companies and medical institutions in decentralised decision-making will invest less effort in quality and service improvement to maximise their own profits. This is because drug quality and services are respectively the responsibility of different entities, and both sides have a "free-rider" mentality, hoping that the other party will invest more effort, ultimately leading to a decline in the optimal level of drug quality and service.

Inference **3:** When $0 < c < \frac{k_1qA^2(2k_1k_2l - k_1\gamma^2 - k_2\theta^2)}{2l[k_1^2A^2(2k_2l-\gamma^2) - k_1k_2\theta^2(8k_2^2l^2 - 6k_2l\gamma^2 + \gamma^4) - k_2^3l\theta^4]}$ and $2k_1k_2l - k_1\gamma^2 - k_2\theta^2 > 0$, then $p^{C*} < p^{D*}$.

Among them, $A = 4k_2l - \gamma^2$.

Inference 3 states that the optimal selling price of drugs under centralised decision-making is not always superior to the optimal decision value under decentralised decision-making. This depends on factors such as the unit procurement cost for the non-profit GPO, drug quality, and service level sensitivity coefficients. For a non-profit GPO to lower costs in the supply chain, the unit procurement cost of drugs must be below a certain level. Otherwise, the non-profit GPO would not achieve a balance between income and expenses by charging contract management fees to drug manufacturers and may face the risk of exiting the drug supply chain.

The above proposition clearly indicates that the optimal profit of the supply chain under decentralised decision-making is always less than that under centralised decision-making. This suggests that drug manufacturers and healthcare institutions need to improve the three aspects of drug: sales price, drug quality, and service level through centralised decision-making, considering the design of reasonable contracts to achieve coordination between the two parties. Under these contracts, drug manufacturers can improve drug quality, and healthcare institutions can enhance drug service levels, which ultimately leads to patients feeling more confident, secure, cost-effective, and comfortable, while also improving the therapeutic effects of the drugs.

5. Analysis of contractual coordination effects

5.1. Analysis of cost-sharing contractual coordination effects

In a pharmaceutical group purchasing supply chain, drug manufacturers' efforts to improve drug quality can enhance the efficacy and safety of drugs and provide patients with better treatment outcomes and security. While this can enhance the competitiveness of drug manufacturers and increase their market share, it can also increase patients' trust in drugs and promote the rational use of medications; thereby motivating healthcare institutions to incentivise drug manufacturers to improve drug quality and share the costs associated with these efforts.

Based on the relevant literature [33,36], we introduce a contract for sharing the costs of drug quality. The coordination mechanism for this contract is as follows. The medical institution takes the initiative to bear a proportion t of the drug quality costs; namely, the medical institution independently bears the service cost k_2g^2 and a portion of the drug quality cost $tk_1\beta^2$, whereas the pharmaceutical manufacturer bears the remaining drug quality cost $(1-t)k_1\beta^2$, where $0 < t < 1$. At this point, the profit functions of the pharmaceutical manufacturer, non-profit GPO, and medical institution can be expressed after introducing a cost-sharing contract as Equations (16)–(18) respectively.

$$\pi_1^{'} = w(1-\delta)(q - lp + \theta\beta + \gamma g) - (1-t)k_1\beta^2 \tag{16}$$

$$\pi_2^{'} = (w\delta - c)(q - lp + \theta\beta + \gamma g) \tag{17}$$

$$\pi_3^{'} = (p-w)(q - lp + \theta\beta + \gamma g) - k_2g^2 - tk_1\beta^2 \tag{18}$$

Proposition 3. *By solving the equations of* $\frac{\partial\pi_1^{'}}{\partial w} = 0$, $\frac{\partial\pi_1^{'}}{\partial\beta} = 0$, $\pi_2^{'} = 0$, $\frac{\partial\pi_3^{'}}{\partial p} = 0$, *and* $\frac{\partial\pi_3^{'}}{\partial g} = 0$ *simultaneously, the optimal wholesale price, optimal quality level, optimal selling price, optimal service level, and optimal contract management fee rate of drugs under the cost-sharing contract can be obtained as* Equations (19)–(23) *respectively*.

$$w^{M*}=\frac{k_1q(t-1)(4k_2l-\gamma^2)+ck_2l\theta^2}{l\left[2k_1(t-1)(4k_2l-\gamma^2)+k_2\theta^2\right]} \tag{19}$$

$$\beta^{M*}=\frac{k_2\theta(2cl-q)}{2k_1(t-1)(4k_2l-\gamma^2)+k_2\theta^2} \tag{20}$$

$$p^{M*}=\frac{(6k_2l-\gamma^2)\left[k_1q(t-1)(4k_2l-\gamma^2)+ck_2l\theta^2\right]}{l(4k_2l-\gamma^2)\left[2k_1(t-1)(4k_2l-\gamma^2)+k_2\theta^2\right]} \tag{21}$$

$$g^{M*}=\frac{r\left[k_1q(t-1)(4k_2l-\gamma^2)+ck_2l\theta^2\right]}{(4k_2l-\gamma^2)\left[2k_1(t-1)(4k_2l-\gamma^2)+k_2\theta^2\right]} \tag{22}$$

$$\delta^{M*}=\frac{cl\left[2k_1(t-1)(4k_2l-\gamma^2)+k_2\theta^2\right]}{k_1q(t-1)(4k_2l-\gamma^2)+ck_2l\theta^2} \tag{23}$$

Consequently, under a cost-sharing contract, the respective profits of the pharmaceutical manufacturers and medical institutions can be derived as Equations (24) and (25) respectively.

$$\pi_1^{M*}=\frac{k_1k_2q(t-1)(q-2cl)}{2k_1(t-1)(4k_2l-\gamma^2)+k_2\theta^2} \tag{24}$$

$$\pi_3^{M*}=\frac{k_2\left[k_1^2q^2A^2(t-1)^2-k_1k_2A\theta^2\left(2clq-6clqt+4c^2l^2t+q^2t\right)+c^2k_2^2l^2\theta^4\right]}{A\left[2k_1A(t-1)+k_2\theta^2\right]^2} \tag{25}$$

Where, $A=4k_2l-\gamma^2$.

Inference **4:** (1) When $0<t<\frac{k_2\theta^2C}{2B}-\frac{1}{2}\sqrt{\frac{k_2\theta^2(q-2cl)^2[4B+k_2\theta^2D]}{B^2}}+1$ holds, $\beta^{M*}>\beta^{D*}$, $g^{M*}>g^{D*}$, and $\pi_1^{M*}>\pi_1^{D*}$.

(1) When $0<t<\frac{(8k_1k_2l-2k_1\gamma^2-k_2\theta^2)[k_2\theta^2q+4cl(4k_1k_2l-k_1\gamma^2-k_2\theta^2)]}{k_1(4k_2l-\gamma^2)[4k_1q(4k_2l-\gamma^2)-k_2\theta^2(q+2cl)]}$ holds, $\pi_3^{M*}>\pi_3^{D*}>0$.

Inference 4 suggests that after the introduction of cost-sharing contracts, when a medical institution bears a proportion of the medication quality cost that is not too high, the optimal medication quality and service level, as well as the profits of both the medication production enterprise and the medical institution, are higher than the optimal decision value under the decentralised decision-making model. Therefore, sharing medication quality costs with medication production enterprises is a mutually beneficial partnership for medical institutions. Through this approach, the medication production enterprise can garner support and assistance from medical institutions, enhance the quality of medication, and further improve its competitiveness in the market by obtaining higher-quality medication supply, improving the therapeutic efficacy of the medication, and enhancing patient satisfaction. However, when a medical institution bears a proportion of the medication quality cost that is too high, it may result in negative profits for the medical institution because it must bear excessive quality costs. Therefore, a reasonable cost-sharing approach can achieve Pareto improvement, in which both parties can benefit and effectively control and reduce the costs and risks of the medical institution, thereby attaining a better cooperative outcome.

Inference **5:** (1) When $0<t<\frac{k_2\theta^2C}{2B}-\frac{1}{2}\sqrt{\frac{k_2\theta^2(q-2cl)^2(4B+k_2\theta^2D)}{B^2}}+1$ holds, $p^{M*}>p^{D*}$.

Where, $B=k_1q^2(4k_2l-\gamma^2)$, $C=4c^2l^2-6clq+q^2$, and $D=4c^2l^2-8clq+q^2$.

Inference 5 suggests that after the introduction of cost-sharing contracts, when a medical institution bears a relatively low proportion of the medication quality cost, the optimal selling price of the medication is higher than the optimal decision value under the decentralised decision-making model. Medical institutions share the cost of improving the quality of medication production with the medication production enterprise, primarily to improve the quality and safety of medication and ensure the safety of patient medication usage. Although this cooperative relationship can improve medication quality, it does not always result in lower medication prices. This is because medication prices are not only related to quality but also to various factors, such as production costs. Medication production enterprises must invest significant amounts in R&D, production, personnel, and other costs to produce high-quality medications. Therefore, although a medical institution sharing the cost of improving medication quality with the medication production enterprise can improve the quality and safety of medication, it may not always directly reduce the selling price of the medication.

5.2. Analysis of the coordinating role of "cost-sharing-quantity discount" combination contracts

After verification, although cost-sharing contracts can achieve Pareto improvement in drug quality, service levels, and profits of drug manufacturers and medical institutions, they cannot coordinate the supply chain system or reduce drug sales prices. Quantity discount contracts can reduce production costs and stimulate sales by reducing prices. To solve this problem, it is necessary to introduce quantity discount contracts based on cost-sharing contracts to reduce drug prices and coordinate the supply chain system, ensuring the long-term and effective operation of the drug group procurement supply chain.

Based on the quantity discount model of Ingene and Parryn [37], the wholesale price of drugs is defined as $w_1=w-dQ$ [38], where

d represents the discount rate for drug quantity, and $0 < d < 1$. At this point, the profit functions of drug manufacturers, non-profit GPOs, and medical institutions can be expressed after introducing a "cost-sharing-quantity discount" contract.

$$\pi_1^{''} = (1-\delta)(q - lp + \theta\beta + \gamma g)[w - d(q - lp + \theta\beta + \gamma g)] - (1-t)k_1\beta^2 \tag{26}$$

$$\pi_2^{''} = \delta(q - lp + \theta\beta + \gamma g)[w - d(q - lp + \theta\beta + \gamma g)] \tag{27}$$

$$\pi_3^{''} = [p - w - d(q - lp + \theta\beta + \gamma g)](q - lp + \theta\beta + \gamma g) - k_2 g^2 - tk_1\beta^2 \tag{28}$$

Similarly, using reverse induction, the optimal drug quality β^{T*}, optimal service level g^{T*}, and optimal selling price p^{T*} of the drug can be obtained by combining Equation (27) with the first-order conditions obtained by optimising Equations (26) and (28). The drug quality, service level, and selling price under the "cost-sharing-quantity discount" composite contract are consistent with those under central decision-making, i.e., $\beta^{T*} = \beta^{C*}$, $g^{T*} = g^{C*}$, $p^{T*} = p^{C*}$, which leads to conclusion 6.

Inference 6 : Under the conditions of $2k_2l - 3\gamma^2 \geq 0$, $2k_1k_2l - k_1\gamma^2 - k_2\theta^2 > 0$, and $(t,\ d) = \left(\frac{2cl[k_1(\gamma^2-4k_2l)+k_2\theta^2]}{k_1q(\gamma^2-4k_2l)+ck_2l\theta^2}, \frac{(4k_1k_2l-k_1\gamma^2)(2cl-q)-ck_2l\theta^2}{4k_1k_2l^2(cl-q)}\right)$, the supply chain can achieve centralised decision-making through a combined contract of "cost-sharing-quantity discount".

Inference 6 suggests that the drug group purchasing supply chain can achieve system optimisation when the coordination parameters of the combination contract meet certain conditions. Cooperation between healthcare institutions and drug manufacturers in the cost-sharing of drug quality can promote the improvement of drug quality and enhance patient drug effectiveness and satisfaction. At the same time, non-profit GPOs can sign quantity discount contracts, which allow healthcare institutions to purchase drugs at a more favourable price by purchasing a larger quantity to better meet their procurement needs. Healthcare institutions share the cost of improving drug quality with drug manufacturers and sign quantity discount contracts with non-profit GPOs to obtain higher-quality drug supplies, reduce procurement costs, and improve patient drug effectiveness and satisfaction, while drug manufacturers can enhance market competitiveness and receive higher profits by enhancing drug quality. Therefore, this cooperation model can achieve Pareto optimality and a win-win effect.

6. Numerical simulation

To verify the correctness and effectiveness of the conclusions obtained by the theoretical analysis, a numerical analysis was conducted based on the model hypothesis and by setting relevant parameters, to reflect the above inferences more intuitively. Drawing on the assumptions of Pu et al., Han & Wang [30,39], and the actual situation of China's pharmaceutical market, this paper sets parameter $q = 50$, $c = 5$, $k_1 = 2$, and $k_2 = 1$.

6.1. The impact of each parameter on the optimal decision under decentralised decision-making

Plotting the impact of the drug sales price sensitivity factor on the optimal decision values under decentralised decision-making, given $\gamma = 1$ and $\theta = 1$, with l as the x-axis, yields Fig. 2. Similarly, plotting the effect of the drug quality sensitivity factor on the optimal decision values, given $\gamma = 1$ and $l = 2$, with θ as the x-axis, yields Fig. 3. Finally, plotting the influence of the drug service level sensitivity factor on the optimal decision values, given $\theta = 1$ and $l = 2$, with γ as the x-axis, yields Fig. 4. From Figs. 2–4, it is easy to see that the optimal prices, quality, and service levels of drugs as well as the optimal profits of drug manufacturers and medical institutions

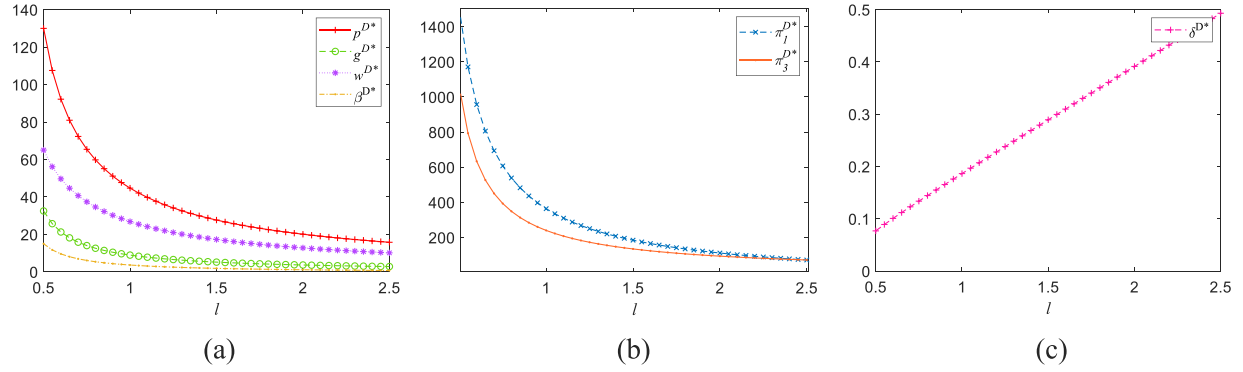

Fig. 2. The impact of drug sales price sensitivity factor on optimal decision values under decentralised decision-making
(a) The impact of drug sales price sensitivity factor on optimal wholesale price, quality, sales price, service level. (b) The impact of drug sales price sensitivity factor on optimal profits. (c) The impact of drug sales price sensitivity factor on optimal contract management fee rate for drugs.

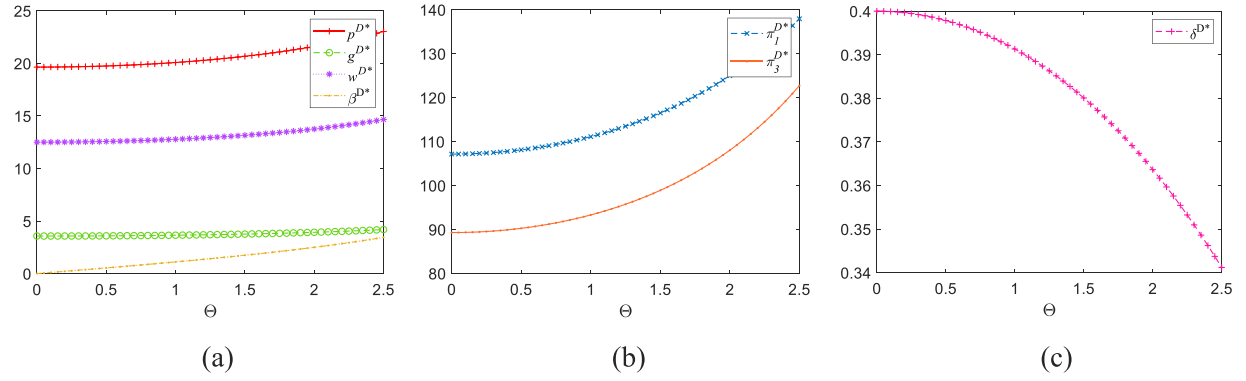

Fig. 3. The impact of drug quality sensitivity factor on optimal decision values under decentralised decision-making
(a) The impact of drug quality sensitivity factor on optimal wholesale price, quality, sales price, service level. (b) The impact of drug quality sensitivity factor on optimal profits. (c) The impact of drug quality sensitivity factor on optimal contract management fee rate for drugs.

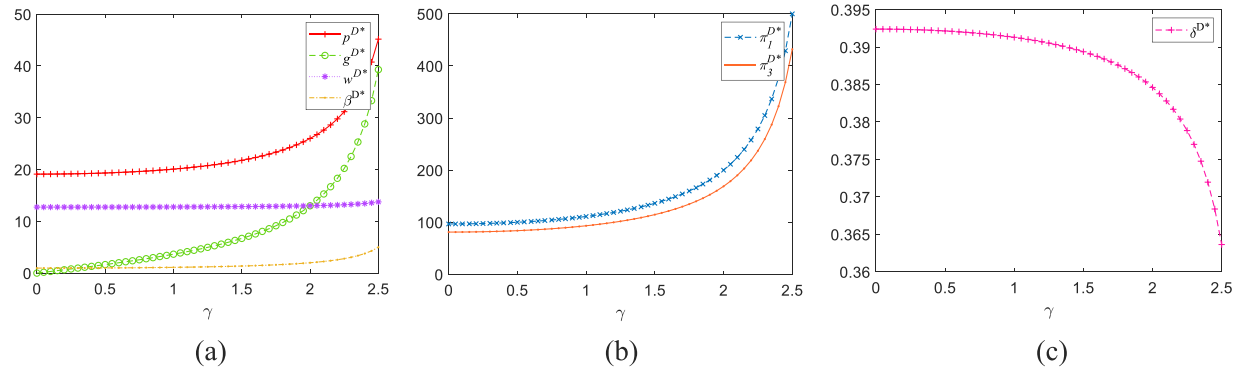

Fig. 4. The impact of drug service level sensitivity factor on optimal decision values under decentralised decision-making
(a) The impact of drug service level sensitivity factor on optimal wholesale price, quality, sales price, service level. (b) The impact of drug service level sensitivity factor on optimal profits. (c) The impact of drug service level sensitivity factor on optimal contract management fee rate for drugs.

are positively correlated with the sensitivity factors of drug quality and service levels. However, they are negatively correlated with the sensitivity factor of the drug sales price. Furthermore, it can be concluded that the optimal contract management fee rate of the non-profit GPO is positively correlated with the drug sales price sensitivity factor but negatively correlated with the drug quality and service level sensitivity factors.

6.2. *Comparison of optimal decisions under decentralised and centralized decision-making*

$\gamma = 1$ and $\theta = 1$ were set, and the optimal decision values under decentralised and centralised decision-making were plotted using l as the horizontal axis. Fig. 5 show that the optimal quality and service level of drugs and the total profit of the supply chain under centralised decision-making are better than those under decentralised decision-making. However, Fig. 5 shows that when the unit procurement cost of the non-profit GPO is lower than a certain level, the optimal selling price of drugs under centralised decision-making is lower than that under decentralised decision-making.

6.3. *Comparison of the optimal decision values under decentralised decision-making and cost-sharing contract coordination*

$\gamma = 1$, $\theta = 1$, and $l = 2$ are set, and the optimal decision values under decentralised decision-making and cost-sharing contract coordination are plotted with t as the horizontal axis. It can be seen from Fig. 6 that introducing a cost-sharing contract can improve drug quality and service level, and increase the profit of drug manufacturers. However, Fig. 6 shows that a cost-sharing contract cannot lower the selling price of the drugs. At the same time, it can be seen from Fig. 6 that when the ratio of quality cost shared by medical institutions is low, it can increase the profit of medical institutions and achieve a "win-win" effect. When it exceeds a certain level, medical institutions share too much of the drug manufacturers' quality costs, resulting in their own profits being less than zero.

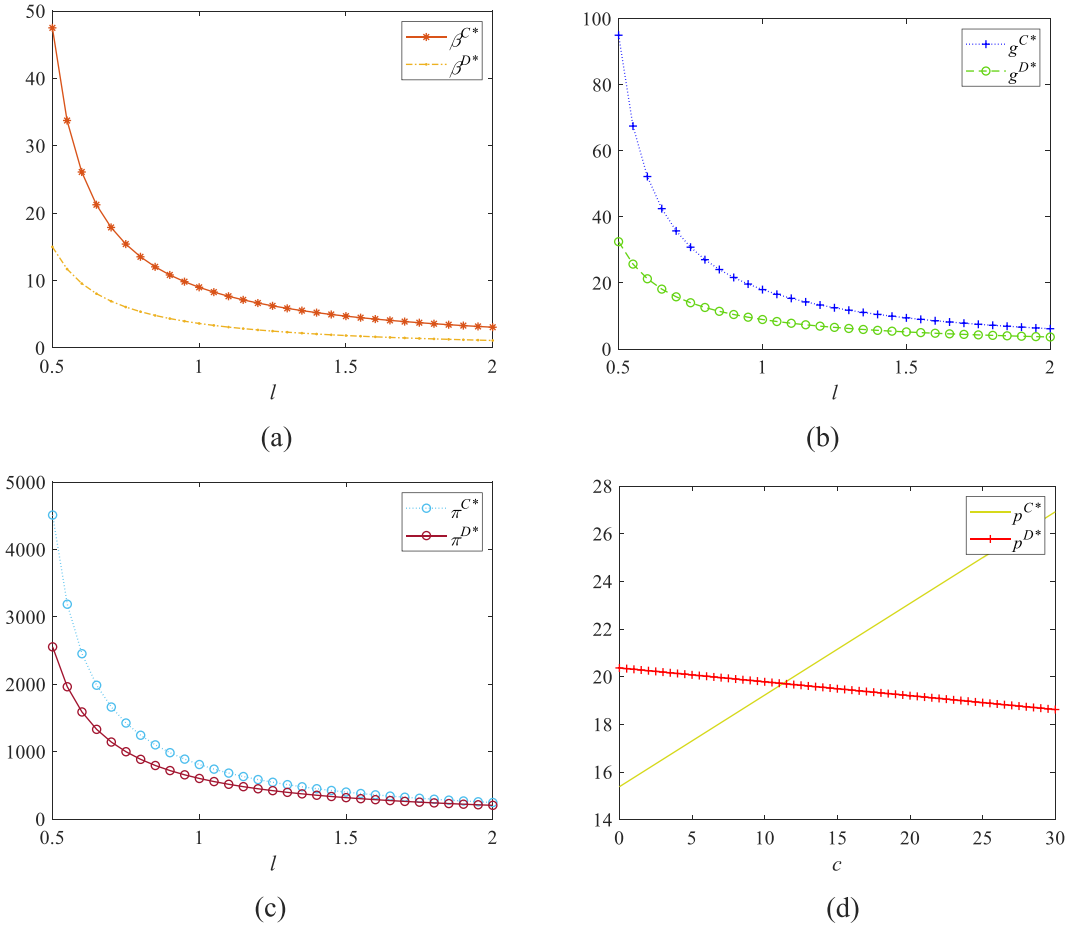

Fig. 5. Comparison of the optimal decision values under decentralised and centralized decision-making
(a) The impact of drug sales price sensitivity factor on optimal quality under decentralised and centralized decision-making. (b) The impact of drug sales price sensitivity factor on optimal service level under decentralised and centralized decision-making. (c) The impact of drug sales price sensitivity factor on optimal profits under decentralised and centralized decision-making. (d) The impact of unit drug procurement cost on optimal sales price under decentralised and centralized decision-making.

6.4. Comparison of optimal decisions under the coordination of centralized decision-making and combined contracts

The passage refers to the plot of $\gamma = 1, \theta = 1$, and $l = 2$, with t and d as the horizontal and vertical axes, respectively, and p, β, and g as the vertical axes to represent the optimal decision values under centralised decision-making and coordinated contract operations. According to Fig. 7, there always exists a corresponding (t, d) that enables the optimal decision values achieved under a joint contract operation to reach a state of centralised decision-making. Through simulation, when $(t, d) = (0.3359, 0.3768)$, it is possible to make $\beta^{T*} = \beta^{C*}$, $g^{T*} = g^{C*}$, $p^{T*} = p^{C*}$, and thereby achieve the Pareto optimal state of the drug group procurement supply chain.

7. Conclusion

This study focuses on the research scenario that integrates value-based healthcare objectives with the pharmaceutical group purchasing model, delineates value-based healthcare objectives in pharmaceutical group purchasing from three perspectives: drug sales price, drug quality, and service level. We construct a three-level pharmaceutical group purchasing supply chain consisting of drug manufacturers, medical institutions, and non-profit drug group purchasing organisations, and introduce cost-sharing contracts and "cost-sharing-quantity-discount" contracts to analyse the impact of factors such as drug sales price, quality, and sensitivity of the service level.

The main conclusions are as follows: (1) In the case of satisfying basic assumptions, under decentralised decision-making, the optimal drug prices, quality, and service levels as well as the optimal profits of pharmaceutical manufacturers and medical institutions are positively correlated with drug quality and service level sensitivity factors, but negatively correlated with drug sales price sensitivity factors. However, the optimal contract management fee rate for non-profit GPOs is positively correlated with drug sales price sensitivity factors, but negatively correlated with drug quality and service level sensitivity factors. (2) The optimal drug quality

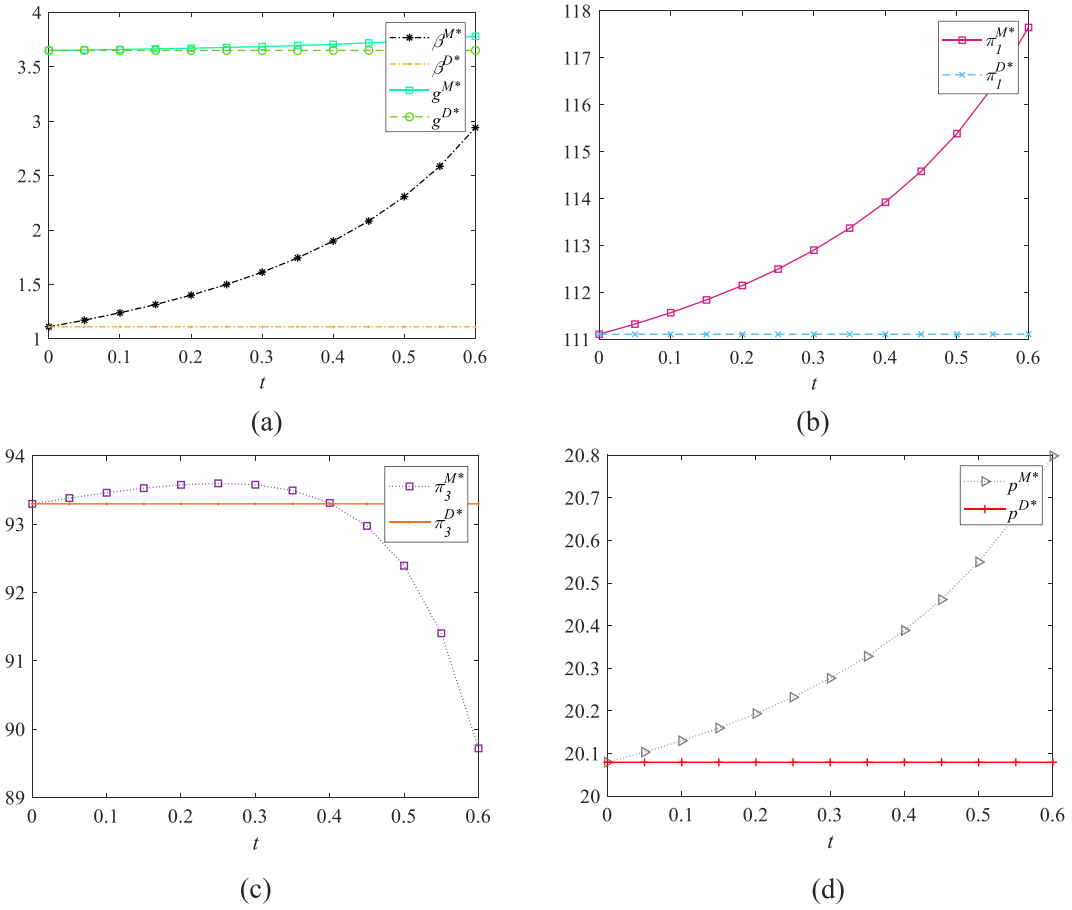

Fig. 6. Comparison of optimal decisions under the coordination of decentralised decision-making and cost-sharing contracts
(a) The impact of "t" on optimal quality and service level under the coordination of decentralised decision-making and cost-sharing contracts. (b) The impact of "t" on optimal profits of the pharmaceutical manufacturers under the coordination of decentralised decision-making and cost-sharing contracts. (c) The impact of "t" on optimal profits of the medical institutions under the coordination of decentralised decision-making and cost-sharing contracts. (d) The impact of "t" on optimal sales price under the coordination of decentralised decision-making and cost-sharing contracts.

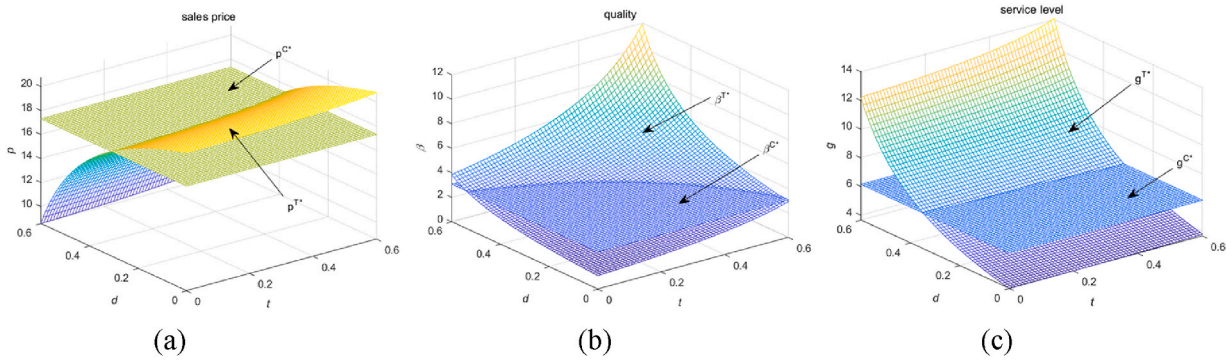

Fig. 7. Comparison of optimal decisions under the coordination of centralized decision-making and combined contracts
(a) Comparison of optimal sales price under the coordination of centralized decision-making and combined contracts (b) Comparison of optimal quality under the coordination of centralized decision-making and combined contracts (c) Comparison of optimal service level under the coordination of centralized decision-making and combined contracts.

and service level in decentralised decision-making and the optimal profits of drug manufacturers and medical institutions will decrease. Under decentralised decision-making, the optimal drug sales price depends on factors such as the unit procurement cost, drug quality, and service level sensitivity of non-profit GPOs, leading to higher or lower optimal drug sales prices than under centralised

decision-making. (3) Introducing cost-sharing contracts can improve the efficiency of the supply chain but cannot achieve supply chain coordination when the proportion of drug quality costs borne by medical institutions is not higher than a certain level. When the proportion of drug quality cost-sharing is higher than a certain level, medical institutions suffer greater losses due to excessive costs. (4) When the parameters of the "cost-sharing-quantity discounts" combination contract meet certain conditions, it can achieve coordination of the drug group procurement supply chain and achieve a win-win result. Therefore, pharmaceutical manufacturers and medical institutions should adopt contracts appropriate to their operational situations and form a sustainable coordination mechanism.

Through research on the abovementioned issues, the following managerial insights can be derived: (1) In the actual operation process of the pharmaceutical procurement supply chain, pharmaceutical manufacturers and healthcare institutions should consider the patients' demand for drug quality and service level. They should increase investment in drug R&D as well as service quality to enhance the level of value-based healthcare. (2) Non-profit GPOs that occupy a dominant position in the pharmaceutical group purchasing supply chain should reasonably control contract management fees to promote enthusiasm for pharmaceutical group purchasing and healthcare institutions to improve drug quality and services. (3) Strengthening the collaboration between pharmaceutical manufacturers, non-profit GPOs, and healthcare institutions can drive the transformation and development of pharmaceutical manufacturers and healthcare institutions towards value-based healthcare. This would promote the establishment of a contractual system in the pharmaceutical procurement market.

This study focuses on government-led non-profit GPO as the research object. In the future, starting with market-oriented, profit-making GPOs, research should be conducted from the perspective of market competition to study supply chain coordination in the presence of multiple market-oriented GPOs. The aim was to explore how policies could be better implemented under different GPO models to reduce drug prices, improve drug quality and service levels, and ultimately enhance supply chain operational efficiency.

Data availability statement

Not applicable.

CRediT authorship contribution statement

Zhao Li: Supervision, Methodology, Funding acquisition, Conceptualization. **Wanzhi Shen:** Writing – original draft, Validation, Software, Investigation, Formal analysis. **Tao Zhang:** Writing – review & editing, Supervision.

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.

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