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Bilevel optimization model for government mixed subsidy strategies in hierarchical healthcare

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A B S T R A C T

To alleviate the problem of long waiting time in general hospitals and underutilization of community hospital resources, this paper explores the effect of government mixed subsidies on patient choice and utilization of community hospital resources. Based on hospital service quality, we establish a benchmark model without government subsidy and a bilevel optimization model in which the government makes the upper-level decisions while the community hospital responds at the lower level. Although the benchmark model is a nonconvex optimization model, we are based on its special structure to propose a globally optimal algorithm. Then, we combine this globally optimal algorithm with the Gauss-Seidel method to solve the bilevel optimization model. Furthermore, we present a sensitivity analysis of some key parameters such as service quality costs, basic medical expenses in community hospitals, and government subsidy budget. Theoretical and numerical results provide the following insights: Government mixed subsidy may improve community hospital service quality and so attract more patients to choose community hospital; Government should focus on fixed fund subsidies to improve community hospital service quality, since hospital service quality is more critical than medical expenses for patient choices; Controlling service quality costs and basic medical expenses in community hospital at a low level and paying more attention to fund subsidies can promote hierarchical healthcare. Meanwhile, the government subsidy budget should be decided aligning with defined societal goals.

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1. Introduction

High-quality healthcare services often encounter the problem of service supply shortages, while the aging population and the imbalance between supply and demand for healthcare services may increase waiting times in healthcare systems, which increases great pressure on public healthcare systems (Guo et al., 2019; Fan et al., 2023). For example, in the United Kingdom, patients often face long delays for elective procedures (e.g., the average waiting time for cataract surgery is 68.8 days and 95 days for knee replacement surgery) (Guo et al., 2019). Canadian patients typically need to wait 18.2 weeks for elective surgeries, while public hospitals in Turkey also suffer from long waiting times (Barua & Fathers, 2014; Haghgou et al., 2024). In recent years, the government and public healthcare organizations have focused their attention on hospital waiting times (Acuna et al., 2022). A common way to reduce waiting times in high-workload hospitals is to direct patients to low-workload hospitals (Niu et al., 2022). For example, in response to the problem that there are too many patients in public hospitals, which exceeds their service capacity and results in reduced patient satisfaction, some scholars use government subsidies to encourage patients to seek treatment in private hospitals (Kaya et al., 2020; Teymourifar et al., 2021). In particular, the problem of hospital efficiency imbalance in China mainly appears between general hospitals and community hospitals (Wang et al., 2021; Li et al., 2024). The healthcare system consisting of high-level general hospitals and low-level community hospitals is called a hierarchical healthcare system (Wang et al., 2021; Zhou et al., 2022; Li et al., 2024). General hospitals are equipped with high-level medical technologies and facilities, being capable of treating all types of patients, including those with serious illnesses and those with mild illnesses. Due to the limitations on the number of the general hospitals and the capacity of medical personnel, general hospitals are mainly responsible for providing specialized services for serious ill and emergency patients (Wang et al., 2021; Li et al., 2024). While, community hospitals represent primary healthcare institutions, which are mainly responsible for the initial diagnosis and management of common and frequent diseases, as well as providing basic health services. However, patients' preference for high-level hospitals makes it common for patients to choose to go to general hospitals for medical treatment, even when dealing with mild illnesses. This tendency results in congestion and pressure on general hospitals to provide medical care, while community hospitals experience underutilization of their medical resources (Wang et al., 2021; Zhou et al., 2022; Li et al., 2024; Li et al., 2025). Therefore, guiding patients to choose appropriate

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hospitals according to their medical conditions is crucial for alleviating congestion in general hospitals and improving the utilization rate of medical resources in community hospitals.

In 2015, to ease pressure on general hospitals and increase the utilization of community hospital resources, China launched the hierarchical healthcare policy to enable patients to choose hospitals suitable to their medical conditions according to the severity of their illnesses. The hierarchical healthcare policy refers to the classification of patients according to the severity of their conditions, with different levels of hospitals providing corresponding treatment services for patients at the corresponding level, which is conducive to achieving a balanced utilization of medical resources and promoting the development of healthcare (Wang et al., 2021). In recent years, the total amount of medical resources in China's community hospitals and other primary hospitals has risen under the impetus of relevant policies and systems, but the hierarchical healthcare policy has not been implemented. Patients' psychological and habitual preference for high-quality hospitals leads to overcrowding in general hospitals with long waiting times for patients and idle medical resources in community hospitals (Liu et al., 2022). Therefore, how to reduce the pressure of high-quality hospitals and guide patients to primary medical and healthcare institutions such as community hospitals is still an urgent issue for healthcare administrators.

There are two main ways to improve the utilization of community hospital resources. One is to encourage patients to choose community hospitals and improve the rate of first diagnosis in community hospitals, and the other is to promote referrals from general hospitals to community hospitals. In general, patients choose hospitals mainly based on their utility from different hospitals and, of course, medical expense is another key factor affecting patients' utility. For this reason, many scholars have studied differentiated reimbursement policies to reduce patients' medical expenses in community hospitals to attract patients to choose community hospitals (Li & Wang, 2021). For example, Wang et al. (2015) summarized government documents and related literature to conclude that the implementation of preferential reimbursement rates at primary healthcare centers can lead patients to choose primary care. Wang et al. (2022) studied the impact of reimbursement policies on multilevel hospital healthcare systems and found that, when the service quality of community hospitals is more sensitive to government's budget, the government reimbursement rate of community hospitals is low. However, it has been found that the effectiveness of differentiated reimbursement policy may be affected by some factors such as perception difference, overtreatment rate, and reimbursement rate (Zhou et al., 2022).

On the other hand, Li et al. (2017) considered the diseases with two distinct phases of care and suggested that rewards may be utilized to incentivize reverse referrals if the cost of the second phase is high. Wang et al. (2021) proved that the performance of the healthcare system may be improved through a referral subsidy strategy, which may achieve a win-win situation among patients, general hospitals, and community hospitals under a certain referral threshold. Li et al. (2021) pointed out that general hospitals are the dominant party in referral collaborations and they proposed a real-time threshold control to manage the flow of referrals for different types of patients. Current research on referrals mainly focus on the capacity of hospital services with relatively few studies based on hospital service quality (Hao et al., 2023). However, hospital service quality is evidently a key factor influencing patients to choose community hospitals.

As stated above, the existing publications on attracting patients to choose community hospitals to improve the utilization of community hospital resources mainly focus on the service capacity of hospitals and the medical care prices, and few researches study from the perspective of service quality. More importantly, relevant studies indicate that one main reason influencing patients to choose community hospitals for initial treatment is patients' dissatisfaction with the service quality provided by community hospitals (Li et al., 2021; Huo et al., 2023). Meanwhile, most patients choose hospitals based on utility they receive from hospitals, and there are many factors that affect the utility of the patient, among which the medical expense and service quality are the main factors (Li & Zou, 2023; Rajan et al., 2019). To guide patients toward community healthcare, the government can, on the one hand, provide support for patients' medical expenses in community hospitals in order to reduce the negative utility brought about by high medical expenses, and, on the other hand, the government can incentivize community hospitals to improve their service quality in order to increase the positive utility brought about by high-quality services. Moreover, the government subsidy strategy is often used to motivate patients to hospitals with low workloads (Kaya et al., 2020; Teymourifar et al., 2021). Motivated by these observations, we study the government mixed subsidy strategy in hierarchical healthcare, which means that the government provides a price subsidy for each patient in community hospitals to reduce healthcare expenses in community hospitals and additionally, the government gives a fixed fund subsidy to community hospitals to support the improvement of service quality provided by community hospitals. We will explore the impact of the government mixed subsidy strategy on patient choice and community hospital service quality from government's perspective and try to answer the following three issues:

(1) Can the government mixed subsidy strategy encourage patients to choose community hospitals and increase the utilization of community hospital resources?
(2) How do community hospital administrators make decisions about the community hospital service quality under the consideration of overall patients' expected utility? How do they respond to the government mixed subsidy strategy?
(3) How do service quality costs affect government mixed subsidy strategy and healthcare system performance?

To address the above questions, we model a healthcare system composed of a community hospital, a general hospital, various patient types, and a government. In this study, hospital service quality encompasses both technical and non-technical aspects. Technical services include accurate diagnosis, effective and timely treatment, and rehabilitation outcomes, while non-technical aspects cover the hospital environment, process efficiency, and the attitude and responsiveness of staff. Although the level of the hospital service quality is multifactorial, in this study, the index is abstracted as a univariate representation, which is consistent with previous modeling optimization studies in the field of medical management. Two mathematical models are considered for two scenarios: One is a no government subsidy model (N model) for the scenario with no government subsidy, in which the community hospital decides the service quality to maximize the overall patients' utility of the community hospital. The other is a leader-follower game model (G model) for the scenario with government mixed subsidy, in which the government serves as a leader to decide the price subsidy and the fixed fund subsidy by maximizing the social welfare and the community hospital serves as a follower to decide the optimal allocation of hospital service quality based on the government subsidies. We find from these models that the government mixed subsidy strategy may effectively encourage patients to choose community hospitals, promote hierarchical healthcare, and improve the utilization of community hospital resources. In addition, some management insights are obtained through sensitivity analysis. Main contributions of this study can be stated as follows:

- Most existing literature takes the government subsidy as a parameter from patients' perspective to study the impact of government price subsidies on patient choice. Differently, this paper considers the game behavior between government and community hospitals from the government's perspective and constructs a bilevel optimization model to study the impact of government mixed subsidy strategy on coordinating hierarchical healthcare.
- We take the hospital service quality as a decision variable, which is different from most previous studies with medical price or service capacity as decision-making variable.
- The N model established in this paper is a nonconvex optimization problem. We are based on its special structure to design an algorithm, which can generate the globally optimal solutions of the model. Then, we apply the above algorithm to design a Gauss-Seidel algorithm to solve the leader-follower game model.

The remainder is organized as follows. Section 2 elaborates on some relevant literature. Section 3 introduces the healthcare system and some preliminaries used in the models. In Section 4, we present two models and give some model transformations. We design algorithms for solving the models in Section 5 and provide a numerical example in Section 6. Section 7 concludes the study and outlines some future work.

2. Literature review

This study is closely related to hospital service quality, government mixed subsidy strategy, and patient choices. Below, we review the relevant literature on these issues.

2.1 Hospital service quality

As one main factor affecting patient choices, hospital service quality has been studied extensively. In particular, Kalaja and Krasniqi (2022) assessed the link between healthcare quality and patient satisfaction in Albania and they concluded that healthcare quality should be improved in terms of the professional skills of healthcare workers, communication between doctors and patients, promptness of health care services, and completeness of medical equipment. Chen et al. (2023) found that the complex properties of healthcare modulate the effectiveness of quality improvement practices, thereby improving hospital service quality. Basile et al. (2024) argued that digital technologies, when combined with big data analysis and risk management, can enhance the overall quality of healthcare services. In addition, Brekke et al. (2010) analyzed how competition influences healthcare quality using the Hotelling model, while Siciliani and Straume (2019) explored hospital competition under fixed prices, focusing on the trade-off between service quality and health equity. In summary, current research on hospital service quality mainly focuses on hospital competition. This paper considers from the perspective of hospital service quality to improve imbalanced utilization of medical resources in healthcare systems.

2.2 Government mixed subsidy strategy

Government mixed subsidy strategy means that the government provides price subsidies for each patient in community hospitals and also provides fund subsidies to community hospitals. Current research focuses on price subsidy strategy or fund subsidy strategy separately in hierarchical healthcare. For the price subsidy strategy, Li and Zou (2023) proposed a patient price subsidy mechanism to mitigate imbalances in hospital supply and demand across different levels in hierarchical healthcare. Wei et al. (2022) explored the optimal referral rate for general hospitals and the corresponding capacity of community hospitals by considering government subsidies for referrals to patients and general hospitals. For the fund subsidy strategy, Li et al. (2021) studied how government subsidies can promote the transfer of high-quality resources from higher-level to lower-level hospitals, showing that prioritizing patient visits in low-level hospitals can enhance overall system performance. Wei et al. (2021) studied the impact of government investment on resources sinking into community hospitals by building a two-stage bilevel queuing model and showed that government's increased investment in community hospitals may improve service capacity and encourage patient utilization of community facilities. On the other hand, Kaya et al. (2020) pointed out that the government can provide fixed payments and fee subsidies to private hospitals and they analyzed optimal contracting parameters and compared the effects of different subsidy contracting mechanisms. Teymourifar et al. (2021)

addressed the problem of long waiting times in public hospitals by proposing government subsidy contract mechanisms such as cost subsidy, mixed subsidy, and differentiated subsidy to improve healthcare system performance.

To sum up, current studies on government subsidies in hierarchical healthcare mainly discuss price subsidy strategy or fund subsidy strategy separately. This study considers from the perspective of the government to explore the impact of government mixed subsidy strategy on the patients' utility in community hospitals and the utilization of community hospital resources.

2.3 Patient choices

Current research on patient choices include two classes. The first class aimed at exploring the factors affecting patient choices through empirical research and relevant studies showed that the factors affecting patient choice include medical expenses, waiting times, hospital service quality, etc., among which the service quality is one main factor affecting patients to choose community hospitals. Arsenault et al. (2020) showed that, in low-income and middle-income countries, hospitals tend to be much better equipped than primary healthcare centers and attracting patients to primary healthcare services is required to improve service quality of primary healthcare centers and increase trust in healthcare centers. Li et al. (2021) used a logistic model to study the situation of patients bypassing primary healthcare facilities for treatment and concluded that improving service quality and strengthening healthcare are important for increasing the utilization of primary healthcare facilities. Feng et al. (2022) found from their study on China's progress in achieving full coverage of basic healthcare services from 2008 to 2018 that patients' trust in primary healthcare facilities and perceptions of healthcare quality were much lower than those of general hospitals.

The second class focused on improving the performance of healthcare systems. Nagurney and Li (2017) constructed a Nash equilibrium model for a competitive network of hospital healthcare procedures consisting of multiple hospitals and multiple healthcare procedures to investigate the effects of price and quality level of hospital healthcare procedures on patient choices. Sá et al. (2019) constructed a dynamic game model of hospital competition and showed that hospital waiting times may affect patient choices and penalty policy may effectively reduce waiting times. Yu et al. (2022) developed a hospital patient utility and profit maximization model for the referral process of a hierarchical hospital system and showed that price subsidies and priority mechanisms may effectively regulate patient choices and attract patients to choose community health centers.

On the basis of the above works, to improve the utilization of community hospital resources, this study explores the impact of service quality, medical expenses, and waiting times on patient choices under government's intervention.

3. Model preliminaries

We consider a hierarchical healthcare system composed of a general hospital, a community hospital, various patient types, and a government, in which the government acts as the external regulator of the system by providing price subsidies for patients in the community hospital and fixed fund subsidies to the community hospital. The policy aims to attract more patients to community hospitals and enhance the utilization of their resources. Table 1 summarizes the symbols used in this study. Based on the threshold of illness severity $\theta \in [0,1]$, patients are divided into two categories, namely, the patients with mild severe conditions (M-type patients) and the patients with more severe conditions (S-type patients). When a patient's illness can be treated at hospitals of different levels, more factors are taken into account in choosing a hospital, which include medical expenses, waiting times, service quality, etc (Wang et al., 2021; Li & Zou, 2023; Li et al., 2021). Due to the severity of their illnesses, S-type patients can only receive treatment at general hospitals, which means that S-type patients must go to the general hospital. Differently, since M-type patients can be treated at both general hospitals and community hospitals, they choose to seek treatment at the general hospital or the community hospital based on their utility obtained in two hospitals (Li & Zou, 2023; Rajan et al., 2019; Savva et al., 2019). Patient utility is mainly affected by the hospital service quality, the patient waiting times, the medical expense, and other factors (Li et al., 2021; Hua et al., 2016).

Note that patient utility generally increases with the improvement of hospital service quality, the decrease in waiting times, and the reduction in patient medical expenses. Therefore, in the absence of government subsidy, the unit utility of a patient choosing the community hospital is defined as $u_1 = m_1 / w_1 - kr_1$ (Kaya et al., 2020; Teymourifar et al., 2021; Haghgou et al., 2024), where m_1 represents the service quality of the community hospital, w_1 represents the waiting time of per patient in the community hospital, k represents the sensitivity of per patient to healthcare expenses, and r_1 represents the medical expenses of per patient in the community hospital. Similarly, we assume the unit patient utility in the general hospital to be $u_2 = m_2 / w_2 - kr_2$, where m_2 represents the service quality of the general hospital, w_2 represents the waiting times of per patient in the general hospital, and r_2 represents the medical expenses of per patient in the general hospital. We denote the severity of one patient's illness by x and assume that x obeys a uniform distribution over [0, 1] (Siciliani & Straume, 2019; Liu et al., 2015). Patient arrivals are assumed to follow a Poisson process with an average rate of λ. Specifically, the arrival rates of M-type (i.e., $x \le \theta$) and S-type (i.e., $x > \theta$) patients are denoted by $\lambda_M = \lambda\theta$ and $\lambda_S = \lambda(1-\theta)$, respectively. In general,

patients with more severe conditions tend to exhibit different arrival characteristics. Here, we assume that $k = \beta_1 - \beta_2 x$, $r_1 = \beta_3 x + \overline{r_1}$, and $r_2 = \beta_3 x + \overline{r_2}$, which $\overline{r_1}$ and $\overline{r_2}$ denotes the basic medical expenses for each patient in the community hospital and the general hospital respectively, and β_{1-3} represent constants with $\beta_2 > 0$. Then, the utility of the patient in the community hospital is $u_1 = m_1 / w_1 - (1-x)(100x + \overline{r_1})$, while the utility of the patient in the general hospital is $u_2 = m_2 / w_2 - (1-x)(100x + \overline{r_2})$.

Table 1
Definitions of set, parameters, and variables

Set	Definition
$\mathcal{I}$	Set of hospitals $\mathcal{I} = \{1,2\}$: $i = 1$ represents the community hospital; $i = 2$ represents the general hospital
Parameter	**Definition**
λ	Average arrival rate of patients in the healthcare system
θ	Threshold of the illness severity
r_i	Medical expenses of each patient in hospital i
$\overline{r_i}$	Basic medical expenses of each patient in hospital i
k	Coefficient of patient sensitivity to medical expenses
u_i / u_i	Unit patient utility in hospital i in the N/G model
p / p	Rate of patients choosing the community hospital in the N/G model
$\overline{m}_1$	Lower bound threshold for service quality in the community hospital
m_2	Service quality in the general hospital
a	Cost coefficient of hospital service quality
μ_i	Average service rate of hospital i
w_i / w_i	Average waiting times at hospital i in the N/G model
c_i	Medical costs of each patient in hospital i
U_i / U_i	Overall patients' utility in hospital i in the N/G model
π_i / $\mathsf{\pi}_i$	Profit of hospital i in the N/G model
$\overline{\pi}_i$	Lower threshold for the profit of hospital i
b_i	Reimbursement provided by the government for each patient in hospital i
B	Upper threshold of government subsidy budget
α	Patient utility weight
H / H	Total government expenditure in the N/G model
S / S	Social welfare in the N/G model
Variable	**Definition**
φ	Price subsidies provided by the government for each patient in the community hospital
T	Fixed fund subsidies provided by the government to the community hospital
m_1	Service quality of the community hospital

In the absence of government subsidy, M-type patients will prefer the community hospital when its utility exceeds that of the general hospital, which means $x < (\beta_1 - ((m_1 w_2 - m_2 w_1) / (w_1 w_2 (\overline{r_1} - \overline{r_2})))) / \beta_2$. As $x \sim \mathrm{U}(0,1)$, the proportion of M-type patients choosing the community hospital is given by

$$p = \int_0^{\frac{\beta_1 - \frac{m_1 w_2 - m_2 w_1}{w_1 w_2 (\overline{r_1} - \overline{r_2})}}{\beta_2}} dt = \frac{\beta_1 - \frac{m_1 w_2 - m_2 w_1}{w_1 w_2 (\overline{r_1} - \overline{r_2})}}{\beta_2}, \tag{1}$$

whereas the rate of the M-type patients choosing the general hospital is $1-p$. Their arrival rate in the community hospital is $\lambda\theta p$ and their arrival rate in the general hospital is $\lambda(1-\theta)+\lambda\theta(1-p)=\lambda(1-\theta p)$. Assume that the patients form an M/M/1 queuing system during hospital treatment process, the expected waiting times in the community and general hospitals are $w_1=1/(\mu_1-\lambda\theta p)$ and $w_2=1/(\mu_2-\lambda(1-\theta p))$ respectively, where μ_1 and μ_2 denote the average service rates of the community hospital and the general hospital respectively. By substituting them into Eq. (1), we have

$$p=\frac{(\overline{r_1}-\overline{r_2})\beta_1-m_1(\mu_1-\lambda\theta p)+m_1(\mu_2-\lambda(1-\theta p))}{(\overline{r_1}-\overline{r_2})\beta_2}. \tag{2}$$

Then, in the case of no government subsidy, the proportion of the M-type patients choosing the community hospital is

$$p=\begin{cases}0 & , \text{ if } \dfrac{(\overline{r_2}-\overline{r_1})\beta_1+m_1\mu_1+\lambda m_2-m_2\mu_2}{(\overline{r_2}-\overline{r_1})\beta_2+\lambda\theta(m_1+m_2)}\le 0\\ \dfrac{(\overline{r_2}-\overline{r_1})\beta_1+m_1\mu_1+\lambda m_2-m_2\mu_2}{(\overline{r_2}-\overline{r_1})\beta_2+\lambda\theta(m_1+m_2)} & , \text{ if } 0\le\dfrac{(\overline{r_2}-\overline{r_1})\beta_1+m_1\mu_1+\lambda m_2-m_2\mu_2}{(\overline{r_2}-\overline{r_1})\beta_2+\lambda\theta(m_1+m_2)}\le 1\\ 1 & , \text{ if } \dfrac{(\overline{r_2}-\overline{r_1})\beta_1+m_1\mu_1+\lambda m_2-m_2\mu_2}{(\overline{r_2}-\overline{r_1})\beta_2+\lambda\theta(m_1+m_2)}\ge 1\end{cases} \tag{3}$$

Therefore, in the case of no government subsidy, the proportion of the M-type patients choosing the community hospitals is

$$p=\frac{(\overline{r_2}-\overline{r_1})\beta_1+m_1\mu_1+\lambda m_2-m_2\mu_2}{(\overline{r_2}-\overline{r_1})\beta_2+\lambda\theta(m_1+m_2)}. \tag{4}$$

Similarly, under the government mixed subsidy strategy, the medical expense of per patient in the community hospital becomes $r_1-\varphi$, where φ is the price subsidy provided by the government for each patient in the community hospital. Then, the unit patient utility in the community hospital and the general hospital are $u_1=m_1/w_1-(\beta_1-\beta_2 x)(\beta_3 x+\overline{r_1}-\varphi)$ and $u_1=m_1/w_1-(\beta_1-\beta_2 x)(\beta_3 x+\overline{r_2})$ respectively, where w_1 and w_2 denote the waiting times of per patient in the community hospital and the general hospital under the government mixed subsidy strategy, respectively. When the utility of the M-type patients in the community hospital is greater than the utility in the general hospital (i.e., $u_1>u_2$, which means $x<(\beta_1-((m_1w_2-m_2w_1)-(w_1w_2((\overline{r_1}-\varphi)-\overline{r_2}))))/\beta_2$), they should choose the community hospital and so the rate of the M-type patients choosing the community hospital under the government mixed subsidy strategy is

$$p=\frac{\beta_1-\dfrac{m_1w_2-m_2w_1}{w_1w_2((\overline{r_1}-\varphi)-\overline{r_2}))}}{\beta_2}, \tag{5}$$

while the proportion of the M-type patients choosing the general hospital is $1-p$. Substituting the waiting times in the community hospital and the general hospital $w_1=1/(\mu_1-\lambda\theta p)$ and $w_2=1/(\mu_2-\lambda(1-\theta p))$ into (5) yields

$$p=\frac{(\overline{r_2}-(\overline{r_1}-\varphi))\beta_1+m_1\mu_1+\lambda m_2-m_2\mu_2}{(\overline{r_2}-(\overline{r_1}-\varphi))\beta_2+\lambda\theta(m_1+m_2)}. \tag{6}$$

As public healthcare institutions operate as non-profit entities, each hospital aims to maximize the expected utility of its patients while satisfying a minimum profit requirement (Li et al., 2021). The overall patient utility is defined as the product of the number of patients treated and the unit patient utility. Accordingly, in the absence of government subsidy, the overall patient utility of the community hospital is $U_1=\lambda\theta p u_1$, while the overall patients' utility of the general hospital is $U_2=\lambda(1-\theta p)u_2$. Similarly, under the government mixed subsidy strategy, the overall patients' utility of the community hospital is $U_1=\lambda\theta p u_1$ and the overall patients' utility of the general hospital is $U_2=\lambda(1-\theta p)u_2$. Due to $x\sim U(0,1)$, the overall patients' expected utilities for two hospitals in the cases of no government subsidy and government mixed subsidy strategy are respectively

$$\mathbb{E}(U_1)=\lambda\theta p(m_1(\mu_1-\lambda\theta p)-((\beta_1-\frac{\beta_2}{2})\overline{r_1}+\frac{\beta_3(3\beta_1-2\beta_2)}{6})), \tag{7}$$

$$\mathbb{E}(U_2)=\lambda(1-\theta p)(m_2(\mu_2-\lambda(1-\theta p))-((\beta_1-\frac{\beta_2}{2})\overline{r_2}+\frac{\beta_3(3\beta_1-2\beta_2)}{6})), \tag{8}$$

$$\mathbb{E}(\mathrm{U}_1) = \lambda\theta\mathrm{p}(m_1(\mu_1 - \lambda\theta\mathrm{p}) - ((\beta_1 - \frac{\beta_2}{2})(\overline{r_1} - \varphi) + \frac{\beta_3(3\beta_1 - 2\beta_2)}{6})), \tag{9}$$

$$\mathbb{E}(\mathrm{U}_2) = \lambda(1-\theta\mathrm{p})(m_2(\mu_2 - \lambda(1-\theta\mathrm{p})) - ((\beta_1 - \frac{\beta_2}{2})\overline{r_2} + \frac{\beta_3(3\beta_1 - 2\beta_2)}{6})). \tag{10}$$

A hospital's profit is the income from treating patients minus service costs (Kaya et al., 2020; Teymourifar et al., 2021; Haghgou et al., 2024). In the case of no government subsidy, the profit functions of the community and general hospitals are given as

$$\pi_1 = \lambda\theta p(b_1 + \beta_3 x + \overline{r_1} - c_1) - am_1^2, \tag{11}$$

$$\pi_2 = \lambda(1-\theta p)(b_2 + \beta_3 x + \overline{r_2} - c_2) - am_2^2. \tag{12}$$

Here, the first parts are the revenues from treating patients and the second parts are the costs of healthcare services, b_1 and b_2 denote the reimbursements provided by the government for each patient, c_1 and c_2 denote the medical costs of each patient, a denotes the cost coefficient of service quality, m_1 and m_2 denote the service qualities of their own hospitals. Similarly， due to $x \sim \mathrm{U}(0,1)$, the expected profit function for the community hospital and general hospitals are given as

$$\mathbb{E}(\pi_1) = \lambda\theta p(b_1 + \frac{\beta_3}{2} + \overline{r_1} - c_1) - am_1^2, \tag{13}$$

$$\mathbb{E}(\pi_2) = \lambda(1-\theta p)(b_2 + \frac{\beta_3}{2} + \overline{r_2} - c_2) - am_2^2. \tag{14}$$

Under the government mixed subsidy strategy, the government provides a subsidy φ to each patient in the community hospital and a fixed fund subsidy T to the community hospital. Thus, the financial subsidy received by the community hospital from the government for treating each patient is $b_1 + \varphi$ and the revenue received from each patient is $r_1 - \varphi$. Therefore, the profit function of the community and general hospitals are

$$\pi_1 = \lambda\theta\mathrm{p}(b_1 + \beta_3 x + \overline{r_1} - c_1) - am_1^2 + T. \tag{15}$$

$$\pi_2 = \lambda(1-\theta\mathrm{p})(b_2 + \beta_3 x + \overline{r_2} - c_2) - am_2^2. \tag{16}$$

Similarly, under the government mixed subsidy strategy, the expected profit function of the community and general hospitals are

$$\mathbb{E}(\pi_1) = \lambda\theta\mathrm{p}(b_1 + \frac{\beta_3}{2} + \overline{r_1} - c_1) - am_1^2 + T, \tag{17}$$

$$\mathbb{E}(\pi_2) = \lambda(1-\theta\mathrm{p})(\frac{\beta_3}{2} + 50 + \overline{r_2} - c_2) - am_2^2. \tag{18}$$

As the system manager, the government aims to maximize the whole social welfare within budget control, which is influenced by the overall patients' utility and hospital profits of the whole healthcare system. Total government expenditures consist of government reimbursements and subsidies to each patient who visits the community hospital. In the case of no government subsidy, the total government expenditures and social welfare are respectively $H = \lambda\theta p b_1 + \lambda(1-\theta p)b_2$, $S = \alpha(\mathbb{E}(U_1) + \mathbb{E}(U_2)) + \mathbb{E}(\pi_1) + \mathbb{E}(\pi_2)$, where α is a weight parameter to reflect the weighting relationship between overall patients' expected utility and hospital profit in social welfare. Similarly, under the government mixed subsidy strategy, the total government expenditures and social welfare are respectively $\mathrm{H} = \lambda\theta\mathrm{p}(b_1 + \varphi) + \lambda(1-\theta\mathrm{p})b_2 + T$, $\mathrm{S} = \alpha(\mathbb{E}(\mathrm{U}_1) + \mathbb{E}(\mathrm{U}_2)) + \mathbb{E}(\pi_1) + \mathbb{E}(\pi_2)$.

4. The models

As is known to us, due to their strong service capacity, high service quality, and good stability, the general hospitals are the main bearers of diagnosis and treatment of patients in current healthcare systems and this situation will not change in a short period due to changes in the service quality of community hospitals. Therefore, in the subsequent analysis, we treat the service quality m_2 of the general hospital as a fixed parameter and do not discuss the influence of the general hospital, as in Li and Zou (2023) and Wu et al. (2021).

In this section, we first construct a benchmark model (N model) for the no government subsidy scenario to examine community hospital decisions and patient choices. Since this model has a nonconvex fractional term, we use some variable substitution technique to simplify the model and an algorithm is designed in the next section to solve globally optimal solutions. Subsequently, under a government mixed subsidy scheme, we develop a leader-follower game model (G model) with the

government as leader and the community hospital as follower to investigate the impact of subsidies on patient behavior.

4.1 No government subsidy model (N model)

Consider the scenario without government subsidy, where the community hospital is the sole decision-maker and chooses its service quality m_1. Patient arrivals at the community and general hospitals are denoted by $\lambda\theta p$ and $\lambda\theta(1-p)$ respectively. For each patient, the community hospital's revenue comprises the patient's medical payment r_1 and any government reimbursement b_1, while the general hospital generates revenue from the government's reimbursement b_2 and the patient medical expenses r_2. The structure for this case is shown in Fig. 1.

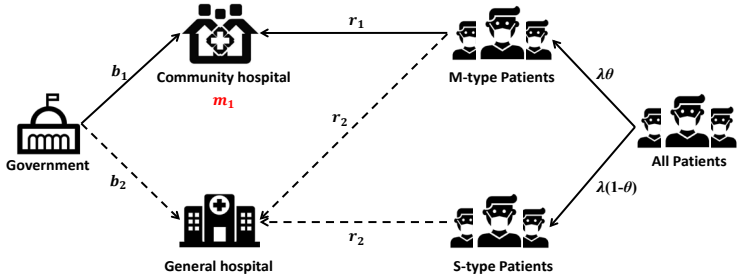


Fig. 1. The structure diagram in the case of no government subsidy

The community hospital aims to maximize its overall patients' expected utility and its decision model (I) can be formulated as

$$\max_{m_1} \quad \mathbb{E}(U_1) = \lambda\theta p(m_1(\mu_1 - \lambda\theta p) - ((\beta_1 - \frac{\beta_2}{2})\overline{r_1} + \frac{\beta_3(3\beta_1 - 2\beta_2)}{6})) \tag{15}$$

$$\text{s.t.} \quad \mathbb{E}(\pi_1) \geq \overline{\pi}_1, \tag{16}$$

$$\lambda\theta p \leq \mu_1, \tag{17}$$

$$\lambda(1-\theta p) \leq \mu_2, \tag{18}$$

$$m_1 \geq \overline{m}_1, \tag{19}$$

where constraint (16) sets a lower bound on the community hospital's expected profit, constraints (17)-(18) restrict patient numbers to the available capacities of the community and general hospitals, and constraint (19) indicates that the community hospital's service quality does not fall below its lower bound threshold for service quality.

Since $p = ((\overline{r_2} - \overline{r_1})\beta_1 + m_1\mu_1 + \lambda m_2 - m_2\mu_2) / ((\overline{r_2} - \overline{r_1})\beta_2 + \lambda\theta(m_1 + m_2))$, the above model is a nonconvex fractional optimization problem, which makes it difficult to find a globally optimal solution. To simplify the model, we solve it to get the following inverse function:

$$m_1 = \frac{(\lambda\theta m_2 + (\overline{r_2} - \overline{r_1})\beta_2)p + (\overline{r_1} - \overline{r_2})\beta_1 - m_2(\lambda - \mu_2)}{(\mu_1 - \lambda\theta p)}. \tag{20}$$

Substituting (20) into model (I) to get a model (II) with variable p as follows:

$$\min_p -\mathbb{E}(U_1) = -\lambda\theta(\lambda\theta m_2 + (\overline{r_2} - \overline{r_1})\beta_2)p^2 + \lambda\theta(m_2(\lambda - \mu_2) + (\overline{r_2} - \overline{r_1})\beta_1 + ((\beta_1 - \frac{\beta_2}{2})\overline{r_1} + \frac{\beta_3(3\beta_1 - 2\beta_2)}{6}))p \tag{21}$$

$$\text{s.t.} \quad -\lambda^3\theta^3(b_1 + \frac{\beta_3}{2} + \overline{r_1} - c_1)p^3 + (2\lambda^2\theta^2\mu_1(b_1 + \frac{\beta_3}{2} + \overline{r_1} - c_1) + a(\lambda\theta m_2 + (\overline{r_2} - \overline{r_1})\beta_2)^2 + \lambda^2\theta^2\overline{\pi}_1)p^2 -$$

$$(\lambda\theta\mu_1^2(b_1 + \frac{\beta_3}{2} + \overline{r_1} - c_1) + 2a(m_2(\lambda - \mu_2) + (\overline{r_2} - \overline{r_1})\beta_1)(\lambda\theta m_2 + (\overline{r_2} - \overline{r_1})\beta_2) + 2\lambda\theta\mu_1\overline{\pi}_1)p +$$

$$am_2^2(\lambda - \mu_2)^2 + \mu_1^2\overline{\pi}_1 \leq 0, \tag{22}$$

$$\max\left\{\frac{\lambda - \mu_2}{\lambda\theta}, \frac{m_2(\lambda - \mu_2) + \overline{m}_1\mu_1}{\lambda\theta(\overline{m}_1 + m_2) + (\overline{r_2} - \overline{r_1})\beta_2}, 0\right\} \leq p \leq \min\left\{\frac{\mu_1}{\lambda\theta}, 1\right\} \text{ if } \lambda\theta(\overline{m}_1 + m_2) + (\overline{r_2} - \overline{r_1})\beta_1 \geq 0,$$

$$\max\left\{\frac{\lambda - \mu_2}{\lambda\theta}, 0\right\} \leq p \leq \min\left\{\frac{\mu_1}{\lambda\theta}, \frac{m_2(\lambda - \mu_2) + \overline{m}_1\mu_1}{\lambda\theta(\overline{m}_1 + m_2) + (\overline{r_2} - \overline{r_1})\beta_{21}}, 1\right\} \text{ if } \lambda\theta(\overline{m}_1 + m_2) + (\overline{r_2} - \overline{r_1})\beta_1 < 0. \tag{23}$$

Model is a one-dimensional optimization problem with quadratic objective and its feasible region is a union of a finite number of closed intervals. Obviously, any global optimal solution must be either an endpoint of the feasible region or a feasible stationary point of the objective function. Therefore, the key to solve the model is to calculate the endpoints of each closed interval and the global optimal solutions can be found by comparing these endpoints with the feasible stationary points. In fact, constraint (22) is a cubic function with respect to the variable p and constraint (23) is a linear constraint, it is feasible

to find the endpoints of each closed interval. The detailed algorithm for solving model (II) is presented in Section 5.

4.2 Government mixed subsidy model (G model)

Consider the case that the government provides mixed subsidies to the community hospital. In this case, the government provides the community hospital with a per-patient price subsidy φ and a fixed funding T. Then, the hospital decides its service quality m_1. Patients arrive at the community and general hospitals at rates $\lambda\theta\mathsf{p}$ and $\lambda\theta(1-\mathsf{p})$ respectively. The community hospital's revenue per patient comprises the patient's medical payment $r_1-\varphi$, the government reimbursement b_1, the government price subsidy φ. In addition, the hospital receives a fixed fund allocation T from the government. The revenue of the general hospital treating each patient consists of the government reimbursement b_2 and the medical expense r_2 of each patient in the general hospital. The structure for this case is shown in Fig. 2.

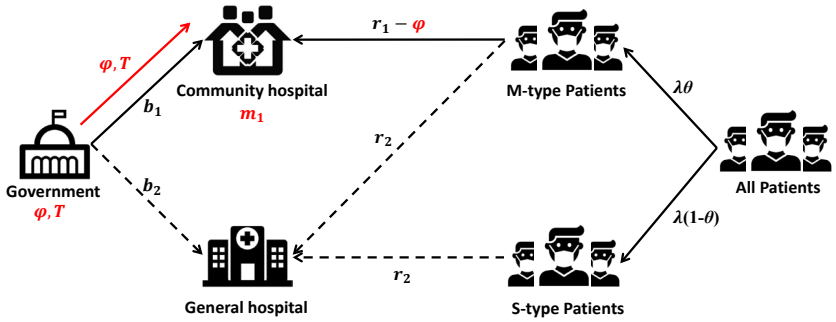


Fig. 2. The structure diagram in the case of government mixed subsidy

Within a reasonable upper bound B for the subsidy budget, the government provides a price subsidy φ for each patient in the community hospital to reduce medical expenses and gives the community hospital a fixed fund subsidy T to incentivize the community hospital to improve its service quality, which in turn attracts patients to choose the community hospitals, with the goal of maximizing social welfare. The community hospital decides its service quality m_1 with the goal of maximizing its overall patients' expected utility. Therefore, we can construct a bilevel optimization model (III) as follows:

$$\max_{\varphi,T} \quad \mathsf{S}=\alpha(\mathbb{E}(\mathsf{U}_1)+\mathbb{E}(\mathsf{U}_2))+\mathbb{E}(\pi_1)+\mathbb{E}(\pi_2) \tag{24}$$

$$\text{s.t.} \quad 0\le\varphi\le \mathrm{E}(r_1), \tag{25}$$

$$\mathsf{H}\le B, \tag{26}$$

$$\max_{m_1} \quad \mathbb{E}(\mathsf{U}_1)=\lambda\theta\mathsf{p}\left(m_1(\mu_1-\lambda\theta\mathsf{p})-\frac{1}{2}r_1^2\right)$$

$$\text{s.t.} \quad \mathbb{E}(\pi_1)\ge\overline{\pi}_1,\ \ \lambda\theta\mathsf{p}\le\mu_1,$$

$$\lambda(1-\theta\mathsf{p})\le\mu_2,\qquad m_1\ge\overline{m}_1,$$

where the upper-level objective function (24) represents the social welfare, constraint (25) implies that the amount of government subsidy is non-negative and does not exceed individual patient medical expenses in the community hospital, and constraint (26) implies that the total government expenditures does not exceed the upper bound B for government subsidy budget.

We use a similar technique to simplify the lower-level problem in model (III). That is, we solve $\mathsf{p}=\frac{(\overline{r}_2-(\overline{r}_1-\varphi))\beta_1+m_1\mu_1+\lambda m_2-m_2\mu_2}{(\overline{r}_2-(\overline{r}_1-\varphi))\beta_2+\lambda\theta(m_1+m_2)}$ to get the inverse function

$$m_1=\frac{(\lambda\theta m_2+(\overline{r}_2-(\overline{r}_1-\varphi))\beta_2)\mathsf{p}+((\overline{r}_1-\varphi)-\overline{r}_2)\beta_1-m_2(\lambda-\mu_2)}{(\mu_1-\lambda\theta\mathsf{p})}$$

and substitute it into model (III) to get the following model (IV) with the variable p:

$$\min_{\varphi,T} \quad -S=\frac{a(p-1)^2}{(\mu_1-\lambda\theta p)^2}\varphi^2-(\frac{2a(((\overline{r}_2-\overline{r}_1)\beta_2+\lambda\theta m_2)p+(\overline{r}_1-\overline{r}_2)\beta_1-m_2(\lambda-\mu_2))(p-1)}{(\mu_1-\lambda\theta p)^2}+\alpha(\lambda\theta p^2-\frac{\lambda\theta p}{2}))\varphi-T+$$
$$am_2^2-\alpha(\lambda(\theta p-1)((\beta_1-\frac{\beta_2}{2})\overline{r}_2+\frac{\beta_3(3\beta_1-2\beta_2)}{6}-m_2(\mu_2+\lambda(\theta p-1)))-\lambda\theta((\overline{r}_2-\overline{r}_1)\beta_1+((\beta_1-\frac{\beta_2}{2})\overline{r}_1+$$
$$\frac{\beta_3(3\beta_1-2\beta_2)}{6})+m_2(\lambda-\mu_2))p+\lambda\theta((\overline{r}_2-\overline{r}_1)\beta_2+\lambda\theta m_2)p^2)+\lambda(\theta p-1)(b_2+\frac{\beta_3}{2}+r_2-c_2)+$$
$$\frac{a(((\overline{r}_2-\overline{r}_1)\beta_2+\lambda\theta m_2)p+(\overline{r}_1-\overline{r}_2)\beta_1-m_2(\lambda-\mu_2))^2}{(\mu_1-\lambda\theta p)^2}-\lambda\theta p(b_1+\frac{\beta_3}{2}+r_1-c_1)$$

$$\text{s.t.} \quad T\ge 0,\ \ 0\le\varphi\le\frac{\beta_3}{2}+\overline{r}_1,$$
$$\lambda\theta p(b_1+\varphi)+T+\lambda(1-\theta p)b_2-B\le 0,$$
$$\min_{p} \quad -\mathbb{E}(U)=-\lambda\theta(\lambda\theta m_2+(\overline{r}_2-(\overline{r}_1-\varphi))\beta_2)p^2+\lambda\theta(m_2(\lambda-\mu_2)+(\overline{r}_2-(\overline{r}_1-\varphi))\beta_1-$$
$$(\beta_1-\frac{\beta_2}{2})(\overline{r}_1-\varphi)+\frac{\beta_3(3\beta_1-2\beta_2)}{6})p$$
$$\text{s.t.} \quad -\lambda^3\theta^3(b_1+\frac{\beta_3}{2}+\overline{r}_1-c_1)p^3+(2\lambda^2\theta^2\mu_1(b_1+\frac{\beta_3}{2}+\overline{r}_1-c_1)+a(\lambda\theta m_2+(\overline{r}_2-(\overline{r}_1-\varphi))\beta_2)^2+$$
$$\lambda^2\theta^2(\overline{\pi}_1-T))p^2-(\lambda\theta\mu_1^2(b_1+\frac{\beta_3}{2}+\overline{r}_1-c_1)+2a(m_2(\lambda-\mu_2)+(\overline{r}_2-(\overline{r}_1-\varphi))\beta_1)(\lambda\theta m_2+$$
$$(\overline{r}_2-(\overline{r}_1-\varphi))\beta_2)+2\lambda\theta\mu_1(\overline{\pi}_1-T))p+am_2^2(\lambda-\mu_2)^2+\mu_1^2(\overline{\pi}_1-T)\le 0,$$
$$\max\left\{\tfrac{\lambda-\mu_2}{\lambda\theta},\tfrac{m_2(\lambda-\mu_2)+\overline{m}_1\mu_1}{\lambda\theta(\overline{m}_1+m_2)+(\overline{r}_2-(\overline{r}_1-\varphi))\beta_2},0\right\}\le p\le\min\left\{\tfrac{\mu_1}{\lambda\theta},1\right\}\quad \text{if}\quad \lambda\theta(\overline{m}_1+m_2)+(\overline{r}_2-(\overline{r}_1-\varphi))\beta_1\ge 0,$$
$$\max\left\{\tfrac{\lambda-\mu_2}{\lambda\theta},0\right\}\le p\le\min\left\{\tfrac{\mu_1}{\lambda\theta},\tfrac{m_2(\lambda-\mu_2)+\overline{m}_1\mu_1}{\lambda\theta(\overline{m}_1+m_2)+(\overline{r}_2-(\overline{r}_1-\varphi))\beta_2},1\right\}\quad \text{if}\quad \lambda\theta(\overline{m}_1+m_2)+(\overline{r}_2-(\overline{r}_1-\varphi))\beta<0.$$

The lower-level problem of model (IV) has the same structure and properties as model (III) and so can be solved efficiently as long as the upper-level variables are given. The upper-level problem of model (IV) has the following property.

Theorem 1. *The upper-level problem of model* (IV) *is a convex optimization problem with respect to the variables* (φ,T).

Proof: The Hessian matrix of the upper-level objective function S in model (IV) with respect to the variables (φ,T) is

$$\nabla^2 S=\begin{bmatrix}\frac{\partial^2 S}{\partial\varphi^2} & \frac{\partial^2 S}{\partial\varphi\partial T}\\ \frac{\partial^2 S}{\partial T\partial\varphi} & \frac{\partial^2 S}{\partial T^2}\end{bmatrix}=\begin{bmatrix}\frac{\partial^2 S}{\partial\varphi^2} & 0\\ 0 & 0\end{bmatrix},$$

where

$$\frac{\partial^2 S}{\partial\varphi^2}=\frac{2a(p-1)^2}{(\mu_1-\lambda\theta p)^2}\ge 0.$$

Obviously, this matrix is positive semidefinite and so the objective function is convex with respect to (φ,T). Since the upper-level constraints are linear, the upper-level problem of model (IV) is a convex optimization problem.

Theorem 1 indicates that the upper-level problem of model (IV) may be solved to get a globally optimal solution. As stated before, the lower-level problem can also obtain a globally optimal solution and thus we can employ the Gauss-Seidel method to solve the model (IV) efficiently. See Section 5 for the detailed algorithm for solving model (IV).

5. Algorithms

In this section, we are based on the special structures of models (II) and (IV) to design effective algorithms to solve them. Recall that the feasible region of model (II) is the union of a finite number of closed intervals in the one-dimensional Euclidean space and hence the key to solve this model is to calculate all endpoints of its feasible region so as to get its global optimal solutions by comparing these endpoints with all feasible stationary points of its objective function. On the basis of this method, we can employ the Gauss-Seidel method to solve the model (IV).

For ease of understanding, we use the following unified form (V) instead of model (II) to introduce the process to calculate all endpoints of its feasible region:

$$\begin{aligned} \min \quad & f(p) \\ \text{s.t.} \quad & g(p) \le 0, \\ & p_1^d \le p \le p_2^d, \end{aligned}$$

where $f(p)$ is a quadratic function, $g(p) = Ap^3 + Bp^2 + Cp + D$ is a cubic constraint function, and $p_1^d \le p \le p_2^d$ is an interval constraint.

5.1 Algorithm for calculating all endpoints of the feasible region of model **(V)**

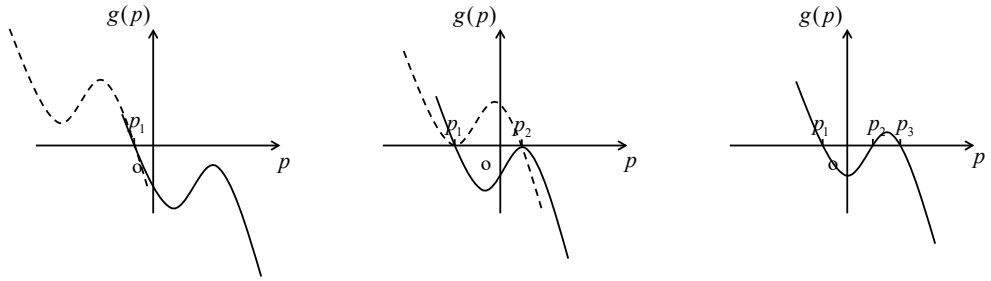
Obviously, the key to calculate the endpoints of the feasible region of model (V) is to find the zero points of the cubic function $g(p)$. Without loss of generality, we assume that $A < 0$ and the case of $A \ge 0$ can be discussed in a similar way.

Consider the first derivative $g'(p) = 3Ap^2 + 2Bp + C$. When $B^2 - 3AC \le 0$, it means $g'(p) \le 0$ and the equality may hold at most one point, which implies that the function $g(p)$ is strictly monotonically decreasing and hence it has only one zero point. When $B^2 - 3AC > 0$, it means that $g'(p) = 0$ has two distinct roots, say $p_1^s < p_2^s$, and there are the following three cases:

(1) In the case of $g(p_1^s) \cdot g(p_2^s) > 0$, $g(p)$ has only one zero point p_1, as shown in Fig. 3(a), where the dashed line denotes the case where the inflection points of the function are on the upper sides of the horizontal axis and the solid line denotes the case where the inflection points are on the lower sides.

(2) In the case of $g(p_1^s) \cdot g(p_2^s) = 0$, $g(p)$ has two zero points $p_1 < p_2$, as shown in Fig. 3(b), where the dashed line denotes the case where the inflection points of the function are on the upper sides of the horizontal axis and the solid line denotes the case where the inflection points are on the lower sides.

(3) In the case of $g(p_1^s) \cdot g(p_2^s) < 0$, $g(p)$ has three zero points $p_1 < p_2 < p_3$, as shown in Fig. 3(c).



(a) $g(p_1^s) \cdot g(p_2^s) > 0$ (b) $g(p_1^s) \cdot g(p_2^s) = 0$ (c) $g(p_1^s) \cdot g(p_2^s) < 0$

Fig. 3. The cases where $B^2 - 3AC > 0$

Based on the above analysis, we can design the following algorithm for calculating the endpoints of the feasible region of model (V).

Algorithm 1	
Step 1	**Analyze the cases of zero points of $g(p)$**
	There are three cases: one/two/three zero points.
Step 2	**Calculate the endpoints of the feasible region of model (V)**
	If $g(p)$ has one zero point, calculate the endpoints according to Case 1 described below.
	If $g(p)$ has two zero points, calculate the endpoints according to Case 2 described below.
	If $g(p)$ has three zero points, calculate the endpoints according to Case 3 described below.

Next, we describe the details about the above three cases.

Case 1: The function $g(p)$ has only one zero point

When $B^2 - 3AC \le 0$ or $B^2 - 3AC > 0$ and $g(p_1^s) \cdot g(p_2^s) > 0$, the function $g(p)$ has only one zero point p_1. The feasible region of model (V) are shown by the solid and dashed lines in Fig. 4, where the solid line represents the image of $g(p)$

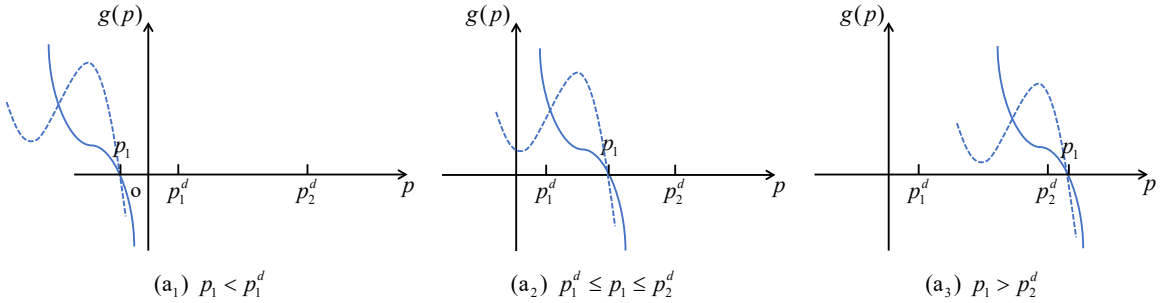
when $B^2-3AC\le 0$ and the dashed line represents the image of $g(p)$ when $B^2-3AC>0$ and $g(p_1^s)\cdot g(p_2^s)>0$. In particular, for simplicity, Fig. 4 only plots the situations where the inflection points are on the upper side of the horizontal axis and the results are consistent with the situations when the inflection points are on the lower side of the horizontal axis.

By taking another constraint $p_1^d \le p \le p_2^d$ into account as well, the feasible region of model (V) has the following three cases:

1) When $p_1 < p_1^d$, the feasible region is $[p_1^d, p_2^d]$, as shown in Fig.4(a_1).

2) When $p_1^d \le p_1 \le p_2^d$, the feasible region is $[p_1, p_2^d]$, as shown in Fig. 4(a_2).

3) When $p_1 > p_2^d$, the feasible region is empty and the model has no solution, as shown in Fig. 4(a_3).



(a_1) $p_1 < p_1^d$ (a_2) $p_1^d \le p_1 \le p_2^d$ (a_3) $p_1 > p_2^d$

Fig. 4. The case where $g(p)$ has only one zero point

Case 2: The function $g(p)$ has two zero points

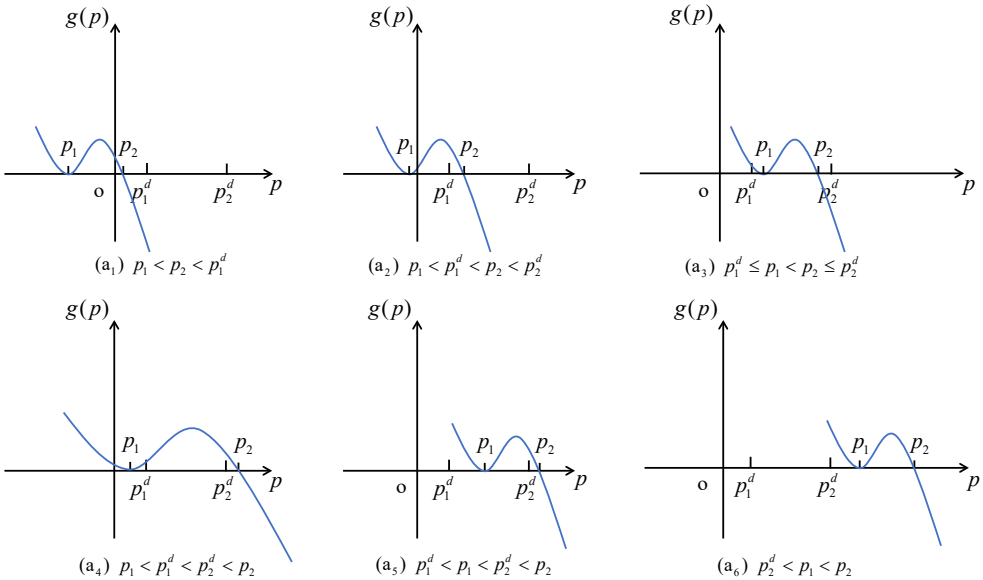
When $B^2-3AC>0$ and $g(p_1^s)\cdot g(p_2^s)=0$, the function $g(p)$ has two zero points $p_1 < p_2$. By taking the constraint $p_1^d \le p \le p_2^d$ into account, the feasible region of model (V) has the following six cases:

- When the inflection points of the function $g(p)$ are on the upper side of the horizontal axis, there are the following three cases:

1) When $p_1 < p_2 < p_1^d$, the feasible region is $[p_1^d, p_2^d]$, as shown in Fig. 5(a_1).

2) When $p_1 < p_1^d < p_2 < p_2^d$ or $p_1^d \le p_1 < p_2 \le p_2^d$, the feasible region is $[p_2, p_2^d]$, as shown in Fig. 5(a_2-a_3).

3) When $p_1 < p_1^d < p_2^d < p_2$ or $p_1^d < p_1 < p_2^d < p_2$ or $p_2^d < p_1 < p_2$, the feasible region is empty and the model has no solution, as shown in Fig. 5(a_4-a_6).



(a_1) $p_1 < p_2 < p_1^d$ (a_2) $p_1 < p_1^d < p_2 < p_2^d$ (a_3) $p_1^d \le p_1 < p_2 \le p_2^d$

(a_4) $p_1 < p_1^d < p_2^d < p_2$ (a_5) $p_1^d < p_1 < p_2^d < p_2$ (a_6) $p_2^d < p_1 < p_2$

Fig. 5. The case where $g(p)$ has two zero points and the inflection point is on the upper side

- When the inflection points of the function $g(p)$ are on the lower side of the horizontal axis, there are the following three cases:

1) When $p_1 < p_2 < p_1^d$ or $p_1 < p_1^d < p_2 < p_2^d$ or $p_1 < p_1^d < p_2^d < p_2$, the feasible region is $[p_1^d, p_2^d]$, as shown in Fig. 6(a_1-a_3).

2) When $p_1^d \le p_1 < p_2 \le p_2^d$ or $p_1^d < p_1 < p_2^d < p_2$, the feasible region is $[p_1, p_2^d]$, as shown in Fig. 6(a_4-a_5).

3) When $p_2^d < p_1 < p_2$, the feasible region is empty and the model has no solution, as shown in Fig. 6(a_6).

Case 3: The function $g(p)$ has three zero points

When $B^2 - 3AC > 0$ and $g(p_1^s) \cdot g(p_2^s) < 0$, the function $g(p)$ has three zero points $p_1 < p_2 < p_3$. The feasible region of model (V) has the following eight cases:

1) When $p_3 < p_1^d$ or $p_1 < p_1^d < p_2^d < p_2$, the feasible region is $[p_1^d, p_2^d]$, as shown in Fig. 7(a_1-a_2).
2) When $p_2 < p_1^d < p_3 < p_2^d$, the feasible region is $[p_3, p_2^d]$, as shown in Fig. (a_3).
3) When $p_1 < p_1^d < p_2 < p_3 < p_2^d$, the feasible region is $[p_1^d, p_2] \cup [p_3, p_2^d]$, as shown in Fig. 7($a_4$).
4) When $p_1^d < p_1 < p_2 < p_3 < p_2^d$, the feasible region is $[p_1, p_2] \cup [p_3, p_2^d]$, as shown in Fig. 7($a_5$).
5) When $p_1^d < p_1 < p_2 < p_2^d < p_3$, the feasible region is $[p_1, p_2]$, as shown in Fig. 7(a_6).
6) When $p_1^d < p_1 < p_2^d < p_2$, the feasible region is $[p_1, p_2^d]$, as shown in Fig. 7(a_7).
7) When $p_2^d < p_1$ or $p_1 < p_2 < p_1^d < p_2^d < p_3$, the feasible region is empty set and the model has no solution, as shown in Fig. 7(a_8-a_9).
8) When $p_1 \le p_1^d \le p_2 \le p_2^d \le p_3$, the feasible region is $[p_1^d, p_2]$, as shown in Fig. 7(a_{10}).

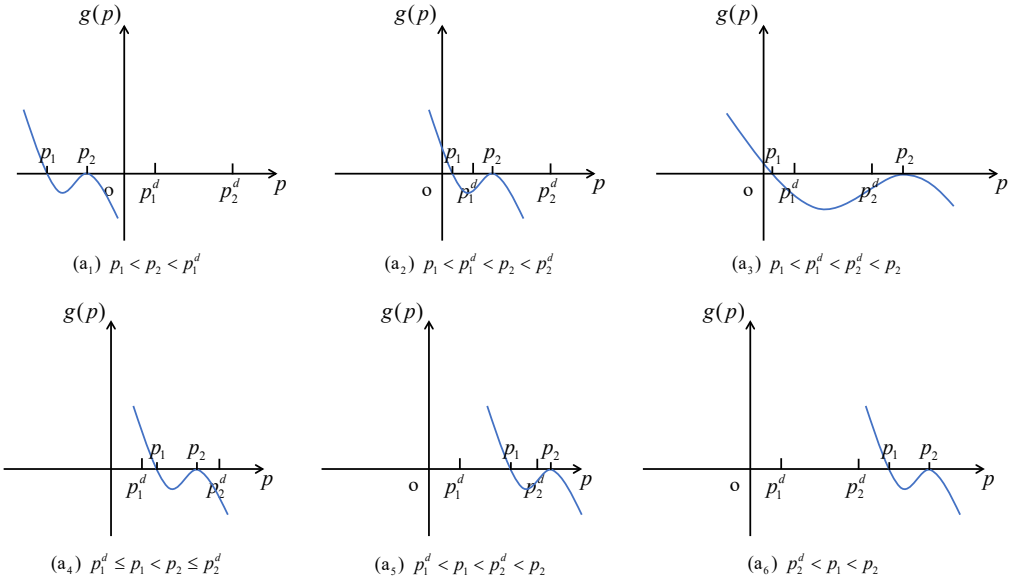


Fig. 6. The case where $g(p)$ has two zero points and the inflection point is on the lower side

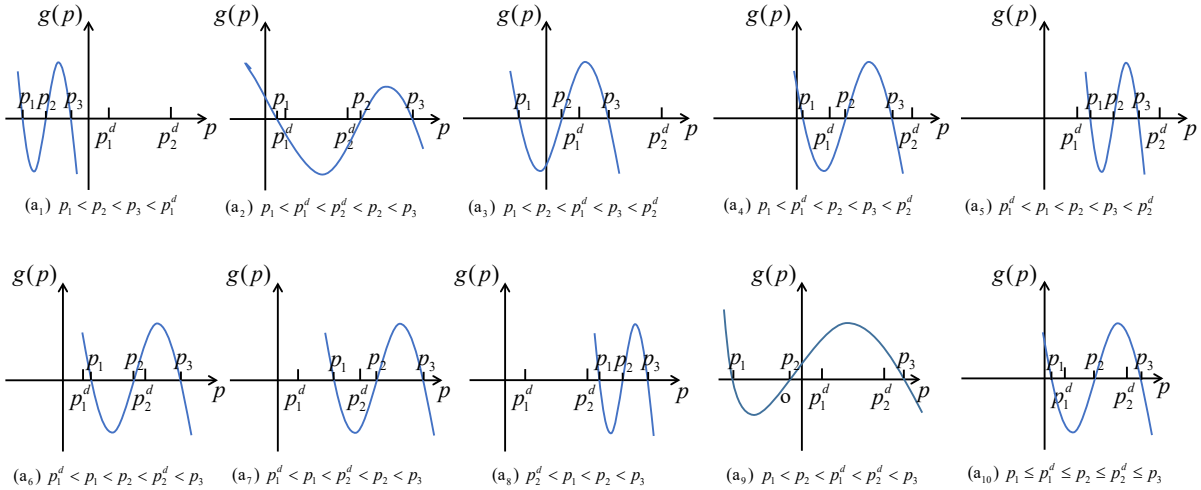


Fig. 7. The case where $g(p)$ has three zero points

Note that, when $A > 0$, it is only necessary to change symmetrically the trend of the cubic function $g(p)$ and then Algorithm 1 can be still applicable. When $A = 0$, the function $g(p)$ is quadratic or linear so that it is relatively easier to calculate the endpoints of the feasible region of model (V). Due to the limited space, we omit these discussions here.

5.2 Algorithm for solving model **(V)**

Since the objective function of model (V) is a quadratic function and its feasible region is a union of a finite number of closed intervals, the global optimal solutions can be obtained by comparing the objective values at the endpoints of the closed intervals and the feasible stationary points. Thus, an effective algorithm can be designed to solve the model (V) as follows.

Algorithm 2	
Step 1	**Solve for stationary point of the objective function** Solve $f'(p)=0$ to obtain the unique stationary point p_0.
Step 2	**Calculate the endpoints of the feasible region** Implement Algorithm 1 to get all endpoints of the feasible region.
Step 3	**Calculate the objective values at the feasible stationary point and the endpoints** If the stationary point p_0 is in the feasible region, then compute the objective value $f(p_0)$; otherwise, disregard this point. Compute the objective values at the endpoints.
Step 4	**Compare all objective values to get the global optimal solutions** Compare the objective values of the feasible stationary point and the endpoints and the points corresponding to the minimum are the globally optimal solutions.

Since model (V) is a generalization of model (II) and the lower-level problem of model (IV), Algorithm 2 can be used to solve these models with the same structure.

5.3 Algorithm for solving model **(IV)**

The bilevel optimization model (IV) under government mixed subsidy strategy can be solved by the Gauss-Seidel method in conjunction with Algorithm 2. That is, given some estimates of the upper-level variables φ and T, Algorithm 2 is called to solve the lower-level problem by fixing these upper-level variables as above to get some globally optimal solution p and then p is fixed as this value the upper-level problem to find the new φ and T, which are then substituted into the lower-level problem. This iteration continues until the terminality condition is satisfied. The specific algorithmic framework is shown in Algorithm 3.

Algorithm 3	
Step 1	**Initialize** Select the initial values φ_0 and T_0, the maximum number of iterations MaxIter, and the accuracy ε. Let $j=0$.
Step 2	**Update** p Take $\varphi=\varphi_j$, $T=T_j$ and call Algorithm 2 to solve the lower-level problem to get p.
Step 3	**Update** $\boldsymbol{\varphi_j}$ **and** $\boldsymbol{T_j}$ Take $\mathsf{p}=\mathsf{p}_j$ and call the fmincon solver in Matlab to solve the upper-level problem to get φ_{j+1} and T_{j+1}. Take $\varphi=\varphi_{j+1}$, $T=T_{j+1}$ and call Algorithm 2 to solve the lower-level problem to get p_{j+1}.
Step 4	**Determining whether the termination conditions are met** If $\left\|(\varphi_{j+1},T_{j+1},\mathsf{p}_{j+1})-(\varphi_j,T_j,\mathsf{p}_j)\right\|\le\varepsilon$, stop. Otherwise, set $j=j+1$ and go to Step 2.

Theorem 1 and Algorithm 2 ensure that both the upper-level and lower-level problems of model (IV) can be solve to get global optimal solutions. Therefore, the above algorithm is well-defined.

6. Numerical experiments

This section presents numerical experiments on sensitivity analysis of key parameters by using Algorithms 2-3 to solve models (II) and (IV). All experiments were run in MATLAB 9.2.0.

6.1 Numerical example

In our experiments, the parameters were selected by following relevant information and data. In particular, the medical expense r_i of each patient and the average arrival rate λ in healthcare system were chosen from China Healthcare Statistics

Yearbook 2022[1]. Based on the notice issued by Shanghai Municipal Bureau of Healthcare Security[2], the reimbursement rates of the community hospital and the general hospital were selected to be 80% and 70% respectively, and then the reimbursements b_i provided by the government for each patient were obtained through calculations. We assumed that the proportion of the M-type patients was 60%, the proportion of the S-type patients was 40%, and so the threshold θ of the illness severity was 0.6. Since the medical costs c_i, the average service rate μ_i, the cost coefficient a of the hospital service quality, the lower bound threshold $\bar{\pi}_1$ for profit of the community hospital, the weight α of patients utility, the upper bound B of the government subsidy budget, the hospital services quality m_i were difficult to obtain real data, we were mainly based on relevant researches (Kaya et al., 2020; Teymourifar et al., 2021). Therefore, The values of these parameters are shown in Table 2, where the unit of the price is yuan and the unit of the number of patients is individual. Meanwhile, for simplification, we conduct numerical experiments under the scenario where $\beta_1 = \beta_2 = 1$ and $\beta_3 = 100$.

Table 2
Relevant parameter configuration

Parameters	r_1	r_2	λ	b_1	b_2	θ	c_1	c_2
Values	0.6	166	329	664	768	110548	752	965
Parameters	μ_1	μ_2	a	B	$\bar{\pi}_1$	α	m_2	$\bar{m}_1$
Values	6e+4	11e+4	1e+5	1e+8	9e+5	0.02	10	2

Using the parameter settings in Table 2, we applied Algorithms 2 and 3 from Section 5 to solve the N and G models, with results summarized in Table 3. In the no-subsidy scenario, 22.37% of patients choose the community hospital. Under the government mixed subsidy scheme, the government opted to provide only fixed fund support to the community hospital rather than subsidizing individual medical expenses, thereby encouraging improvements in service quality. This approach increased the proportion of patients selecting the community hospital, suggesting that fixed funding to enhance service quality may raise both patient utility and overall social welfare. The findings indicate that patients may value higher-quality care more than lower medical costs.

Table 3
Numerical results by different models

Parameters / Models	φ	T	m_1	p / p	$\mathbb{E}(U_1)$ / U	S / S
N model	-	-	3.16	22.37%	2.12e+9	5.06e+7
G model	0	1.88e+7	15.01	54.63%	1.29e+10	2.63e+8

Table 4 reports the values of key performance indicators in the healthcare system under both the no-subsidy and mixed-subsidy scenarios, with time measured in hours. The results indicate that, under the government mixed subsidy scheme, although per-patient medical expenses in the community hospital remain unchanged, its service quality has markedly improved. This enhancement increases patient selection of the community hospital and reduces waiting times at the general hospital (see Table 6). Consequently, the community hospital experiences higher revenue, while the general hospital's profit declines due to fewer patients. Meanwhile, total government expenditures reach the maximum subsidy budget.

Table 4
The values of performance parameters

Parameters / Models	w_1 / W	w_2 / W	π_1 / π	π_2 / π	H / H
N model	0.19	0.61	9.00e+5	7.41e+6	8.33e+7
G model	0.37	0.25	9.00e+5	3.52e+6	1.00e+8

6.2 Sensitivity analysis

In this subsection, we analyze the impact of the key parameters including patient choices, two hospitals' profits, and government's total expenditures on performance indicators. From different perspectives, we selected the thresholds of the service quality cost, the basic medical expenses in the community hospital, and the upper bound of the government subsidy

[1]National Health Commission of the People's Republic of China. China Health Statistical Yearbook. Beijing: Peking Union Medical College Press. 2022. http://www.nhc.gov.cn/mohwsbwstjxxzx/tjtjnj/202305/6ef68aac6bd14c1eb9375e01a0faa1fb/files/b05b3d958fc546d98261d165cea4adba.pdf

[2]Shanghai Municipal Medical Security Bureau. Notice of matters related to the conversion of the city's basic medical insurance to the 2023 medical insurance year. https://www.shanghai.gov.cn/cmsres/9b/9b3cd50f4f2e4b7b9f0573d853cc6e7c/17e43364cea7e0a5a835dfc0 cd2b9560.

budget as the key parameters for sensitivity analysis to provide valuable management insights for government administrators to promote hierarchical healthcare.

6.2.1 Effect of service quality cost

The costs associated with service quality influence hospital profits and the level of service provided, which in turn affect patient choices. Sensitivity analysis results are presented in Fig. 8. Fig. 8(a)–(b) show that, as service quality costs rise, the per-patient price subsidy in the community hospital remains zero under the mixed subsidy policy. However, the fixed fund allocation from the government gradually decreases with increasing costs. Fig. 8(c) illustrates that service quality in both models declines as costs increase, yet the G model consistently maintains higher service quality than the N model. This suggests that the government mixed subsidy strategy enhances service quality, though the gap between the two scenarios narrows as costs grow.

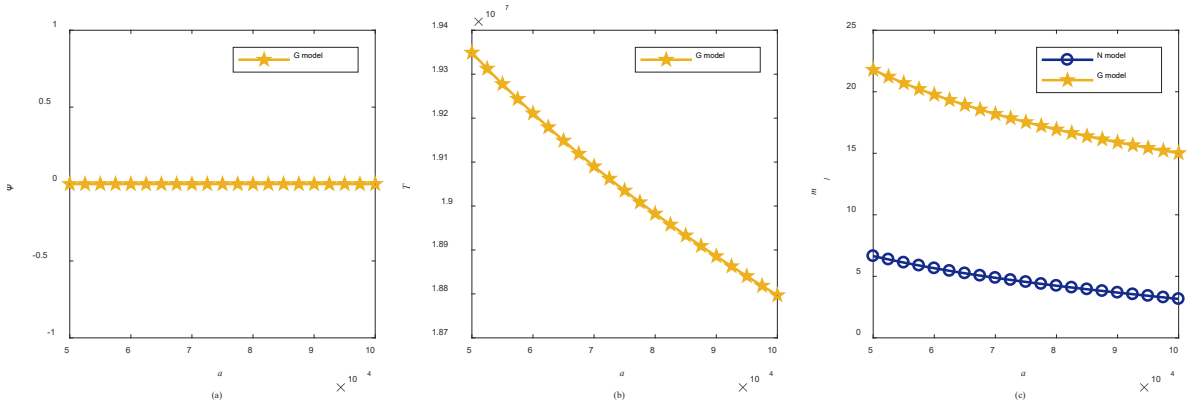


Fig. 8. The impact of service quality costs on equilibrium decision results

Next, we examine how service quality costs influence patient choices and waiting times, as shown in Fig. 9. Fig. 9(a) indicates that an increase in service quality costs leads to a lower proportion of patients selecting the community hospital, suggesting that declines in service quality may deter patients from seeking first treatment there. Comparing the N and G models, the community hospital consistently attracts a higher patient share under the G model, demonstrating that the government mixed subsidy policy encourages patient selection of the community hospital. Fig. 9(b)–(c) show that, as service quality costs rise and fewer patients visit the community hospital, its waiting time decreases, whereas waiting time at the general hospital increases. Nonetheless, the G model exhibits relatively shorter waiting times at the general hospital, implying that mixed subsidies can enhance overall healthcare system performance.

When the service quality costs increase, under the government mixed subsidy strategy, although both the amount of fund subsidies to the community hospital and the number of patients in the community hospital decrease, the service quality costs of the community hospital increase, which results in the profit of the community hospital maintaining at a minimum threshold in both models, as shown in Fig. 10(a). Fig. 10(b) implies that, with the increase of the service quality, the general hospital's profit under two models shows a decreasing trend. Although the number of patients in the general hospital under two models increases, the general hospital's profit decreases since the increase in service quality costs results in high negative profit. The number of patients in the general hospital in model G is smaller than that in model N and so the general hospital's profit under the government mixed subsidy strategy is smaller than that in the case of no government subsidy strategy. From Fig. 10(c), it can be found that, as the service quality costs increase, the overall patients' expected utility of the community hospital under both models tends to decrease, but the overall patients' expected utility of the community hospital in the G model is higher than that in the N model.

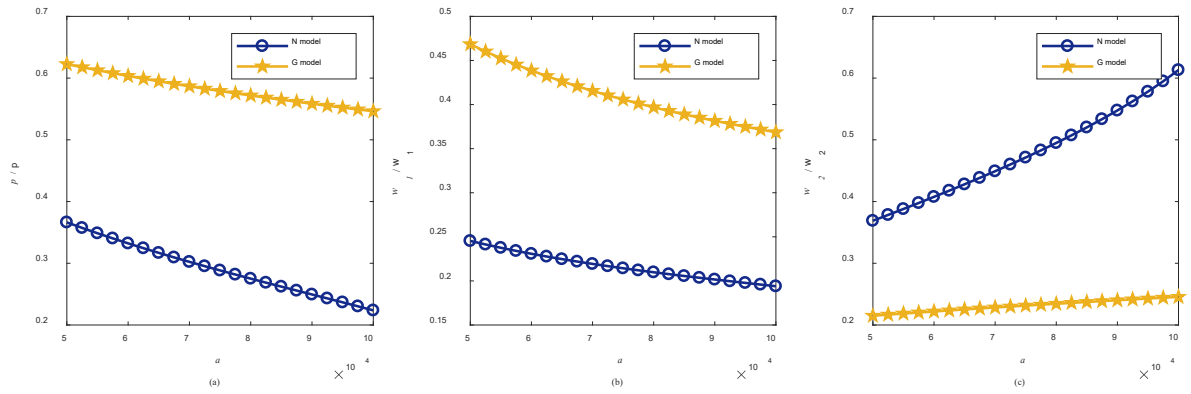


Fig. 9. The impact of service quality costs on patient-related equilibrium performance

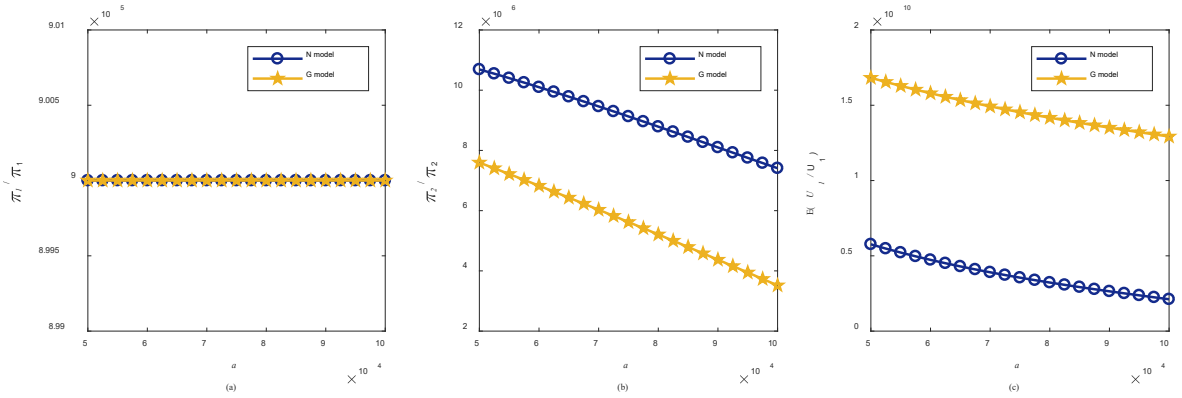


Fig. 10. The impact of service quality costs on hospital-related equilibrium performance

The results related to the impact of service quality costs on total government expenditures and social welfare are shown in Fig. 11. It can be seen that, when the service quality costs increase, the total government expenditures increases in the case of no government subsidy. However, under the government mixed subsidy strategy, when the service quality costs increase, the total government expenditures remain unchanged, reaching the bound of the government subsidy budget, as shown in Fig. 11(b). Moreover, as the service quality costs increase, social welfare tends to decrease in both models, but the social welfare in the G model is higher than that in the N model, which indicates that the government mixed subsidy model may improve social welfare.

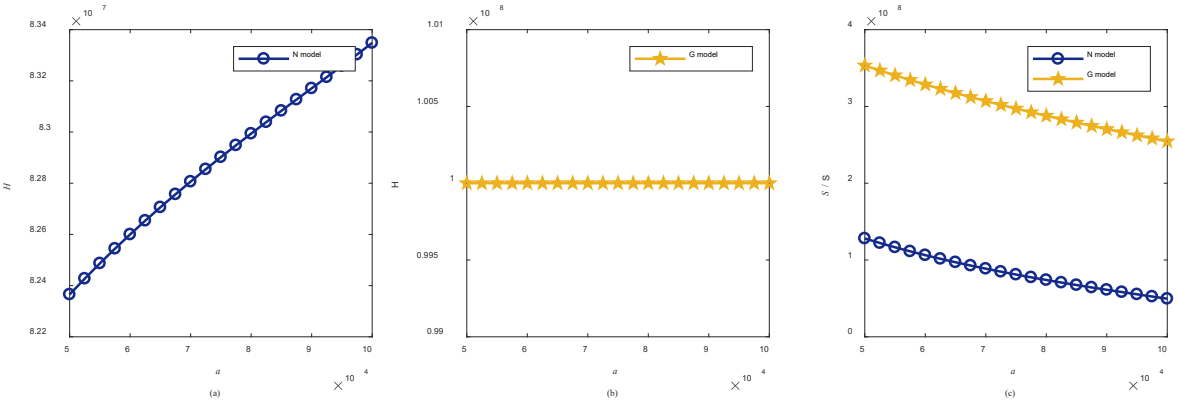


Fig. 11. The impact of service quality costs on government-related equilibrium performance

6.2.2 Effect of basic medical expenses

To streamline the analysis, we conduct a sensitivity study on the community hospital's basic medical costs. As depicted in Fig. 12, increasing costs do not affect the per-patient price subsidy, which remains zero under the mixed subsidy policy, whereas fixed fund allocations increase. Without subsidies, service quality improves continuously with rising expenses, and a similar upward trend is observed under the mixed subsidy policy, albeit to a lesser extent.

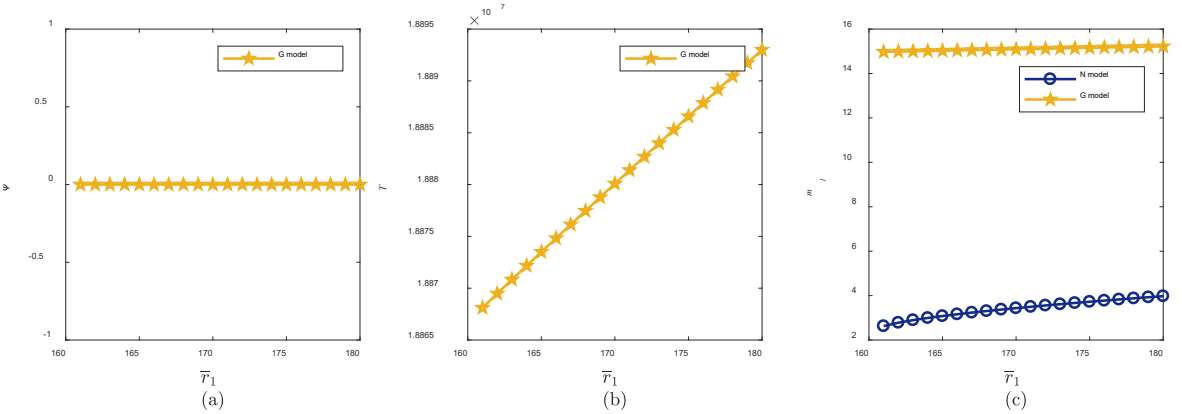


Fig. 12. The impact of basic medical expenses in the community hospital on equilibrium decision results

We next examine how changes in basic medical expenses affect patient decisions and waiting times, as illustrated in Fig. 13. In both models, higher medical expenses are associated with improved service quality at the community hospital, which in

turn increases the proportion of patients selecting it. However, the rate is higher under the government mixed subsidy strategy, as shown in Fig. 13(a). This indicates that the government mixed subsidy strategy is effective in encouraging patients to choose community hospitals for their medical needs. From Fig. 13(b)-(c), it is evident that changes in patient choices result in an increasing trend in waiting times at the community hospital and a decreasing trend in waiting times at the general hospital. Moreover, under the influence of the government mixed subsidy strategy, there is a significant reduction in waiting times at the general hospital.

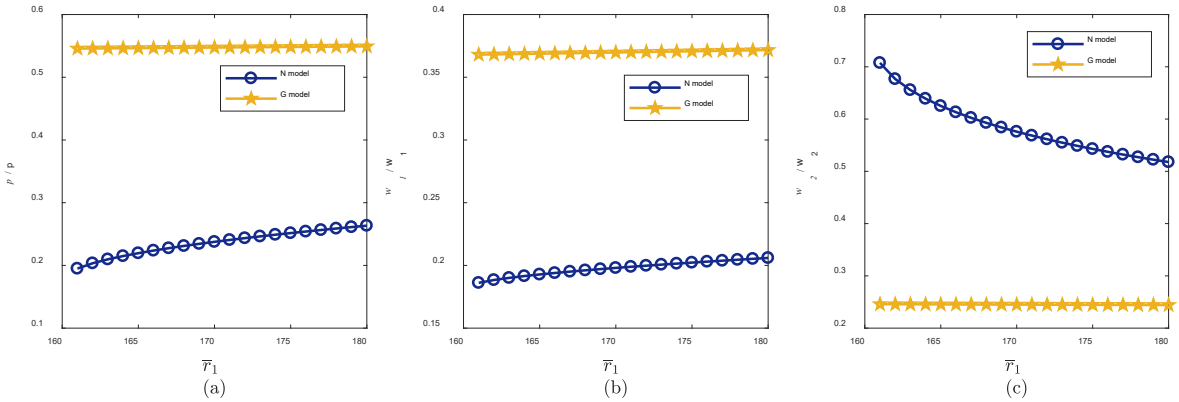


Fig. 13. The impact of basic medical expenses in the community hospital on patient-related equilibrium performance

In the absence of government subsidy, the community hospital's profit reaches the minimum threshold at equilibrium and remains insensitive to increases in basic medical expenses. By contrast, under the mixed subsidy policy, the hospital's profit rises with higher patient numbers and larger fixed fund allocations from the government, as shown in Fig. 14(a). Fig. 14(b) indicates that as community hospital expenses increase, the resulting decline in general hospital patient volume reduces their profits in both scenarios. Although higher medical costs raise patient disutility, the benefits from improved service quality at the community hospital more than offset this effect. Consequently, expected patient utility at the community hospital increases in both models, with the mixed subsidy strategy yielding higher utility, suggesting that this policy supports the hospital's operational objectives.

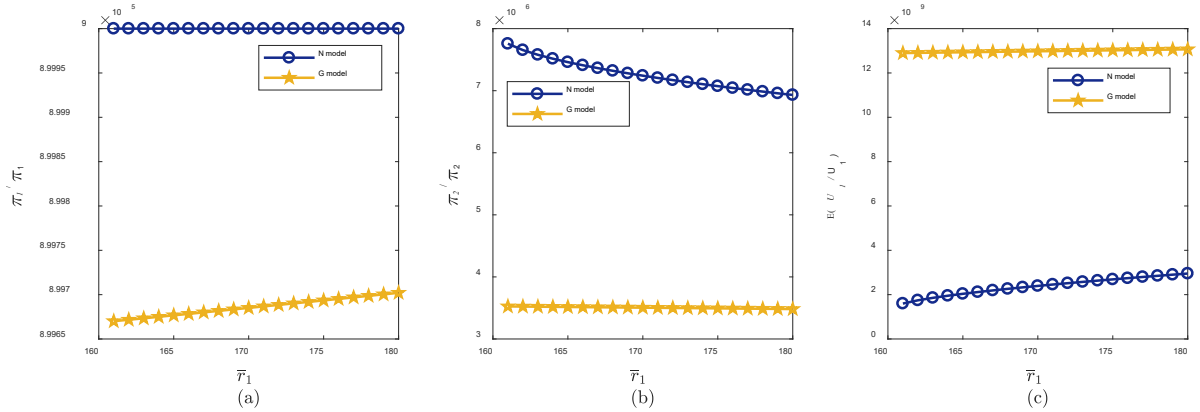


Fig. 14. The impact of basic medical expenses in the community hospital on hospital-related equilibrium performance

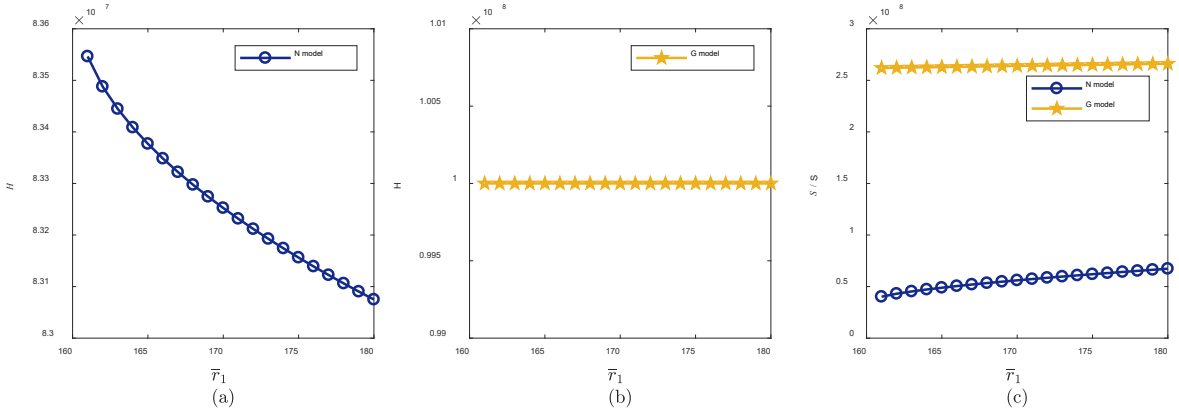


Fig. 15. The impact of basic medical expenses in the community hospital on government-related equilibrium performance

In the N model, changes in the basic medical expenses in the community hospital do not affect the reimbursement expenses

provided by the government to patients at the community and general hospitals. However, the increase in the number of people choosing the community hospital and the lower reimbursement expenses provided by the government for community hospital patients compared to the general hospital result in a downward trend in total government expenditures, as shown in Fig. 15(a). Under the government's mixed subsidy strategy, the total expenditures of the government reach the upper subsidy budget. As can be seen from Fig.15(c), with the increase in basic medical expenses in the community hospital, social welfare continuously rises under both models, and it is higher under the government mixed subsidy strategy. It is noteworthy that by comparing the trends of equilibrium performance under the two scenarios, it can be observed that as the basic medical expenses in the community hospital increase, the overall improvement effect of the government mixed subsidy strategy gradually diminishes.

6.2.3 Effect of government subsidy budget

The efficacy of the government mixed subsidy strategy is significantly influenced by the government subsidy budget. Therefore, this section will analyze the impact of the upper threshold of the government subsidy budget on the equilibrium outcomes and performance of the healthcare service system. Since the government subsidy budget is only present in the government mixed subsidy strategy, this parameter does not affect the no government subsidy scenario. Hence, the analysis primarily focuses on the influence of this parameter on the efficacy of the government mixed subsidy strategy. As illustrated in Fig. 16, with the increase in the upper threshold of the government subsidy budget, under the government mixed subsidy strategy, the fixed fund subsidies provided by the government to the community hospital increase, while the price subsidies for each patient in the community hospital remain unchanged. Concurrently, the service quality of the community hospital shows an upward trend.

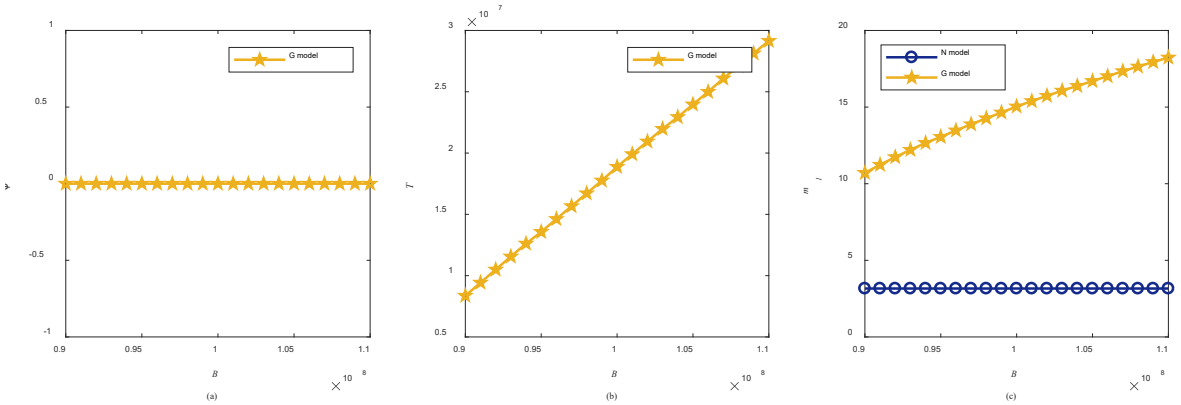


Fig. 16 The impact of government subsidy budget in the community hospital on equilibrium decision results

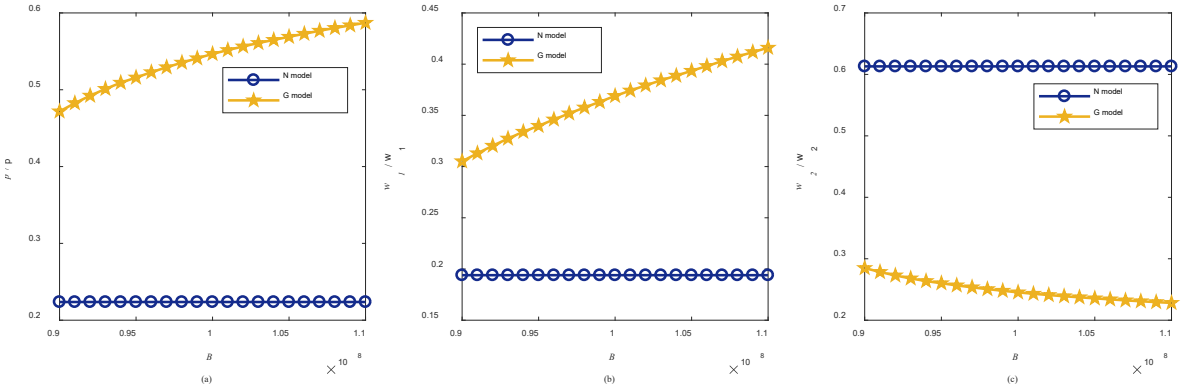


Fig. 17. The impact of government subsidy budget in the community hospital on patient-related equilibrium performance

As the government subsidy budget increases, service quality at the community hospital improves, enhancing patient utility and leading to a higher share of patients choosing the hospital, as shown in Fig. 17(a). With more patients directed to the community hospital and fewer at the general hospital, waiting times at the general hospital decline under the mixed subsidy policy (Fig. 17(c)). Meanwhile, the subsidy budget ensures that waiting times in the community hospital remain below those in the general hospital.

As illustrated in Fig. 18, under the government mixed subsidy policy, community hospital profits decline as the upper limit of the subsidy budget increases, suggesting that additional government funding does not fully offset the costs of enhancing service quality. At the same time, general hospital profits decrease due to a lower patient volume. Despite this, improved service quality at the community hospital raises patient utility, leading to an overall increase in expected patient utility within the hospital, as depicted in Fig. 18(c).

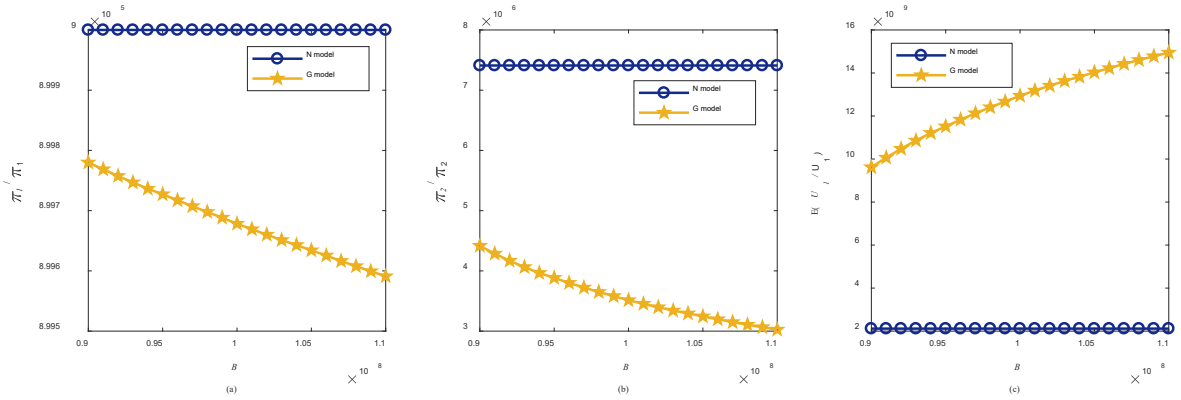


Fig. 18. The impact of government subsidy budget in the community hospital on hospital-related equilibrium performance

As the government subsidy budget continues to rise, the total government expenditures exhibit an upward trend due to the increasing amount of fixed fund subsidies provided to the community hospital, as shown in Fig. 19(b). Under the government's mixed subsidy strategy, although the profits of both community and general hospitals decrease with the increase in the government subsidy budget, the increment in patient utility outweighs the reduction in hospital profits. Consequently, social welfare demonstrates an upward trend, indicating that the government mixed subsidy strategy is beneficial for enhancing social welfare.

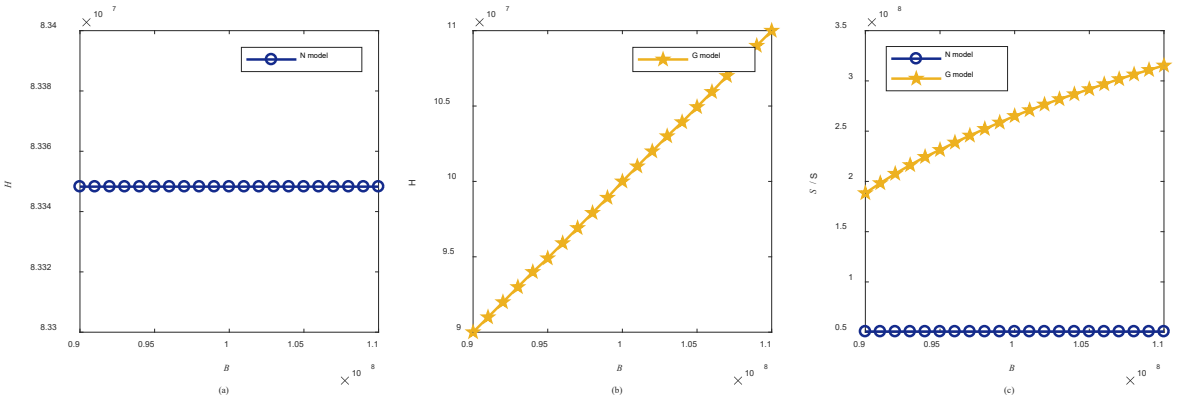


Fig. 19. The impact of government subsidy budget in the community hospital on government-related equilibrium performance

6.2.4 Discussion & management insights

The analysis of service quality costs suggests that as these costs rise, government support increasingly relies on fixed fund subsidies, which tend to grow with higher costs. Due to the minimum profit threshold, community hospital service quality may decline, leading to fewer patients selecting the hospital and longer waiting times at general hospitals. Consequently, both expected patient utility at the community hospital and overall social welfare decrease. Nevertheless, the mixed subsidy policy can enhance the performance of the healthcare system. Management implications include maintaining low hospital service quality costs and prioritizing fixed fund subsidies to elevate community hospital service quality, thereby encouraging first-time patient visits, supporting hierarchical care, and improving social welfare.

Based on the analysis of basic medical expenses at the community hospital, several conclusions can be drawn. As medical expenses rise, the government's per-patient price subsidy remains constant, whereas the total fund allocation gradually increases. In both the N and G models, the community hospital continuously enhances its service quality. This improvement generates positive utility for patients, leading to a higher proportion of patients selecting the community hospital. The shift in patient flow reduces numbers at the general hospital, resulting in shorter waiting times there, while waiting times at the community hospital become longer. Regarding financial performance, in the absence of government subsidies, the community hospital's profits remain at the minimum threshold. Under the mixed subsidy policy, however, profits increase due to higher patient volume and fixed fund support. General hospital profits decline in both scenarios, with a sharper reduction observed when no subsidies are provided. The rise in community hospital patient numbers and improved service quality also contribute to an increase in overall expected patient utility. Total government expenditures decrease continuously without subsidies, whereas they reach the upper limit of the subsidy budget under the mixed subsidy scheme. Social welfare improves within a certain range of basic medical expenses in both models, with higher welfare achieved under the government mixed subsidy policy compared to the no-subsidy scenario. The management implications are clear: when basic medical expenses are relatively high, enhancing service quality and implementing a mixed subsidy approach can encourage patients to seek care at community hospitals, thereby supporting hierarchical treatment. It is important to note, however, that the effectiveness of the

mixed subsidy strategy diminishes as medical expenses continue to increase, suggesting that excessively high expenses do not necessarily produce better outcomes.

Based on the analysis of the government subsidy budget, several conclusions can be drawn. As the subsidy budget increases, the per-patient price support for the community hospital remains zero, while the total fund subsidies allocated to the hospital rise. This additional funding gradually enhances the hospital's service quality, which encourages more patients to choose the community hospital for treatment. The shift in patient flow results in longer waiting times at the community hospital and shorter waiting times at the general hospital. Although both community and general hospitals experience a decline in profits under these conditions, the overall expected utility of patients increases, which offsets the negative impact on hospital revenues and leads to an upward trend in social welfare. The management implications are clear: increasing the government subsidy budget can improve the utilization of community hospital resources, strengthen healthcare system performance, and enhance social welfare. However, the marginal improvement diminishes as the subsidy budget continues to rise, highlighting the importance of setting a reasonable upper limit for subsidies in line with specific policy objectives.

7. Conclusions

In response to the problem of overcrowding in general hospitals, long waiting times for patients, and underutilization of medical resources in community hospitals, we propose a government mixed subsidy strategy to attract patients to choose community hospitals so as to improve the utilization rate of community hospital resources. We first establish a benchmark model for the case of no government subsidy. Under the government mixed subsidy strategy, we establish a leader-follower game model with the government as the leader and the community hospital as the follower. Although the benchmark model is a nonconvex optimization model, we are based on its special structure to propose a globally optimal algorithm. Then, we combine this globally optimal algorithm with the Gauss-Seidel method to solve the leader-follower game model. Furthermore, we present a sensitivity analysis of some key parameters including service quality costs, basic medical expenses in community hospitals, and government subsidy budget to analyze the impact of these parameters on performance of the healthcare system.

The findings of this study indicate that the government's mixed subsidy strategy effectively encourages patients to utilize community hospitals and contributes positively to enhancing their service quality. As a result, this approach benefits patients, the overall healthcare system, and social welfare. To maximize social welfare, the government emphasizes fixed fund subsidies aimed at improving the services offered by community hospitals, thereby incentivizing patient selection. In equilibrium, the policy of providing only fixed fund subsidies without per-patient price support underscores the crucial role of service quality in shaping patient decisions, which appears to outweigh the influence of medical expenses. Sensitivity analyses reveal that higher service quality costs at community hospitals lead to a lower patient selection rate and a decline in overall system performance; however, the mixed subsidy strategy can mitigate these effects and improve healthcare outcomes. Similarly, when basic medical expenses are excessively high, the effectiveness of the mixed subsidy policy is reduced. Moreover, once the government subsidy budget surpasses a certain limit, the incremental benefits of the policy gradually diminish. In conclusion, maintaining low service quality costs and reasonable medical expenses in community hospitals is important, while government managers should focus on providing fixed fund subsidies and promoting patient utilization through the mixed subsidy strategy. This approach can enhance the balanced allocation of healthcare resources. Additionally, the optimal government subsidy budget should be determined strategically, taking into account specific environmental conditions and policy objectives.

The healthcare system considered in this paper is relatively simple. In the future, we may consider the healthcare system consisting of multiple general hospitals and multiple community hospitals. We may also explore the factors affecting patient utility and the indicators affecting hospital service quality and investigate their effect on patient choices to obtain practical management insights from multiple perspectives.

Acknowledgments

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