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SIMULATION STUDY OF REVENUE SHARING IN HEALTHCARE ALLIANCES

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ABSTRACT

Since the referral system of the Chinese hierarchical healthcare delivery system is still developing, patients can go directly to the specialists for all outpatient care, which results in a significant imbalance of patient flow. To balance the patient flow, the general hospital (GH) and the community healthcare center (CHC) form a healthcare alliance. We propose a two-stage game-theoretic approach to study the operations of the healthcare alliance and employ simulation to analyze the revenue sharing in the alliance. In the first-stage game, two providers negotiate fixed proration rates to share the revenue from referral patients. In the second-stage game, the GH makes the capacity allocation decision and the CHC decides referral rates to maximize their own revenues. We first analyze the Nash equilibrium in the second-stage game through simulation, and then back to the simulation of the first-stage game to investigate the revenue sharing rule's feasibility and efficiency.

1 INTRODUCTION

Mismatch between supply and demand is a prevalent problem in Chinese healthcare market. The healthcare delivery system in Chinese urban areas is hierarchical and comprised of the community healthcare center (CHC) and the general hospital (GH). The CHC acts as a primary care provider. However, since China does not set up an explicit gatekeeping system, patients can go directly to the GH for all outpatient care (Liu et al. 2017). The GH can cure most patients while the CHC is only able to cure part of patients with probability of misdiagnosis while dealing with patients with complex symptoms. This results in greater public trust in the GH over the CHC. In addition, because of the price regulation for the public healthcare system, there is no obvious difference in co-pay between these two types of healthcare institution. Lacking good measures for access control, patients have no incentives to visit a CHC prior to consulting a specialist in the GH. Therefore, the number of patients going to the GH exceeds its capacity while the situation of the CHC is just the opposite.

This mismatch seriously impairs the efficiency and the accessibility of the healthcare delivery system. Attracting too many patients with mild illness, the GH may run out of capacity to meet the demand of patients with serious illness, due to the capacity constraint of the GH. However, patients with serious illness are always more profitable than those with mild disease. Therefore, the mismatch prevents the GH from improving its revenue. Whereas, the CHC cannot attract enough demand to get a reasonable utilization of its capacity.

A practice in China to solve this type of mismatch problem is to formulate healthcare alliances, where GHs and CHCs work together to introduce some incentives to encourage more patients visit the CHC prior to seeking care at the GH. In this paper, we study one kind of the incentives, which is the green channel. The green channel means that the GH allocates part of its capacity for the referral patients from the CHC.

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In practice, GHs specially reserve some dedicated appointment slots for the referral patients. These reserved slots are regarded as the service capacity of the green channel. It provides more convenience for patients who visit the CHC firstly, compared with the situation where referral patients need to go through the same process as those who visit the GH directly.

This kind of cooperation has potential to benefit both the GH and CHC. With more patients with mild illness visiting the CHC first, the CHC can achieve a high utilization and obtain a high revenue, and the GH can focus on the diagnosis and treatment of the more profitable patients. To achieve this win-win situation, both GH and CHC need each other. The GH needs to decide how capacity is allocated between two parts. As for the CHC, it needs to control its referral process accordingly.

Though the GH and CHC in China recognize the benefits of this cooperation, they find that there are some barriers in the development of the alliance. Within this alliance, each one wants to maximize its profit. In the decentralized scenario, the alliance always cannot achieve a win-win situation or even result in a worse case. For instance, since the wage of the general practitioner in the CHC does not provide enough incentive to encourage them to take effort to treat patients with mild illness, the green channel still attracts a lot of patients with mild disease. In this case, the GH cannot focus on the serious illness, whereas, dividing its capacity into two parts may reduce its efficiency due to the pooling effects, which is unexpected.

In this paper, we study the collaboration between the GH and the CHC, where the GH decides its capacity for the referral of patients (the green channel) and the CHC controls its referral process. To maximize profit, the GH needs to balance the capacity between two channels, which can affect its demand of two channels. The CHC needs to set its referral rate, considering its limited skill level and the cost due to the probability of mistreatment. To coordinate the CHC and the GH, we consider a contract between them that defines the allocation of the revenue from each referral patient. We want to provide insights into the following questions: 1) Will this type of alliance always result in a revenue gain for both the GH and the CHC? 2) Is there an optimal revenue allocation that leads to the decentralized system achieving the same efficiency as a centralized one?

Simulation is employed to analyze the characteristics of the game because the game theoretical model is too complicated to be solved theoretically. We first analyze the Nash equilibrium in the second-stage game through simulation, and then back to the simulation of the first-stage game to investigate the revenue sharing rule's feasibility and efficiency. By analyzing a non-cooperation game given a fixed revenue sharing contract we obtain the following results. We first show that it is better for the GH to allocating less resources to the green channel than the number of referral patients when the CHC's capacity is not so huge and the CHC is willing to take more effort to treat more patients under specific conditions. In addition, we show the conditions under which the alliance can be formed and when the decentralized system can achieve the same total revenue as there is a central planner managing the alliance.

Several papers study the explicit gatekeeping system which obligates patients to firstly see and get approval from their gatekeeper before visiting a specialist. Shumsky and Pinker (2003) investigate how to incentivize the gatekeeper to choose a system-optimal referral rate. Lee et al. (2012) use the same framework to explore the outsourcing decisions in the gatekeeping system. Freeman et al. (2016) carry out an empirical study and investigate how workload affects gatekeepers' referral decisions in the gatekeeping systems. These models are not suitable for our problem, where the capacity allocation has great impact on the demand of each hospital.

Our paper is also related to service providers' collaborating on capacity. Li and Zhang (2015) studied the benefit of capacity sharing in shipping industries. They compared the capacity reservation model with the passive capacity sharing model. Guo and Wu (2016) studied capacity sharing between two firms that engage in price competition under ex-ante and ex-post capacity sharing price schemes. Hu et al. (2013) adopted a hybrid approach with both cooperative and non-cooperative games and studied the operations of an airline alliance. These papers assume that participations in the alliance provide substitutable service or products. Our paper, on the other hand, considers that the service provided by the CHC and the GH is not fully substitutable. In summary, in this paper we contribute a new model to study the collaboration between two level service providers, which takes both referral process and patients' choice behavior into consideration.

The remainder of this paper is organized as follows. In the next section, we describe our model and lay out the model assumptions. The simulation and the main insights are presented in Sections 3 and 4. We present our conclusions in Section 5.

2 MODEL DESCRIPTION

Considering a hierarchical healthcare delivery system (HDS) consists of two types of service providers: the CHC and the GH, as shown in Figure 1. Let the capacity of the GH and the CHC be 1 and c , respectively. Due to the fact that there are much less GHs than CHCs (From the report of National Health and Family Planning Commission of the People's Republic of China, up to 2016, there were 28 thousand GHs and 928 thousand CHCs in China), we can safely make the assumption $c>1$.

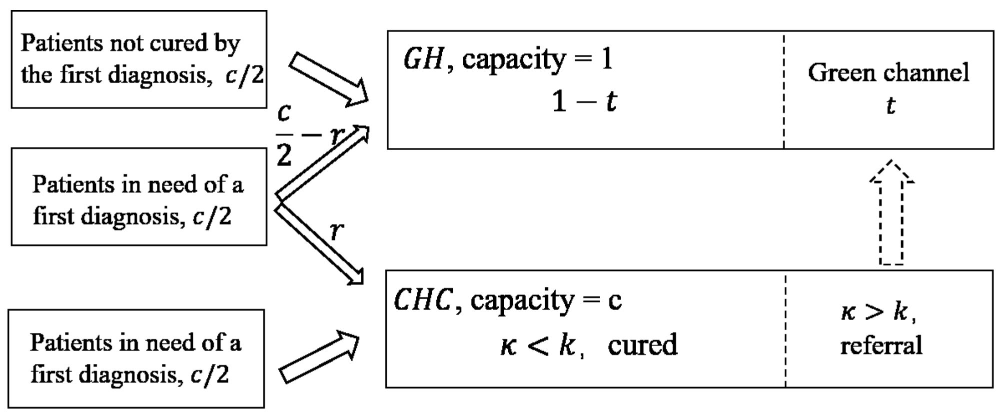

Figure 1: the HDS consisting of the CHC and the GH and the patients' choice

The HDS are faced with two types of patients. One type of patients need the first diagnosis while the other are already diagnosed or treated in the CHC but not cured, behind which is the assumption that patients visiting GHs are assumed to be definitely cured. Considering in reality there are more patients in need of the first diagnosis than those calling for further treatment, let the number of these two types of patients be c and $c/2$ respectively, which is also consistent with the fact that the number of patients going to the GH exceeds its capacity while the situation of the CHC is just the opposite. Therefore, . Let $\kappa \in [0,1]$ be a fractile of patients calling for the first diagnosis, ranked by disease complexity, that is, κ denotes a position in the ranking of patients such that $\kappa \times 100\%$ of patients are less complex. As for the patients who cannot be cured by the CHC, suppose $\kappa = 1$ in that these patients are sure that they cannot be treated in the CHC. However, as for the patients in need of the first diagnosis, the difference between the GH and the CHC is not so significant and they choose to visit the GH and the CHC randomly. Therefore, suppose half of the patients who need the first diagnosis choose the GH while the remaining half choose the CHC and the distribution of their disease complexity of these two parts of patients is the same because when the patients make a choice, they do not have enough knowledge of their disease complexity. In this way, when there is no alliances between the GH and the CHC, i.e. when $r = 0$, the number of patients who choose the CHC is $c/2$ and that of the GH is c, which implies not every patient going to the GH could get access to the treatment. It is worth noting that not all the patients visiting the HDS could be treated by the GH or the CHC. There are two ways of patient loss in these $(3c)/2$ patients every period. One way of patient loss occurs in the registration process to the GH, and the other occurs in the referral process from the CHC to the GH.

Due to the limited capacity of the GH, we need to specify how capacity is allocated among the providers. We assume that, the randomized-rationing rule is employed in the allocation of capacity among the rationed patients (Tirole 1998). That is, the patients who go to the GH are allocated the GH's capacity with equal probability $1/c$.

The profit the provider could make from a patient is positively correlated with the complexity of his disease because in most cases, to cure a patient with more complex needs longer time and more medicine, which means more profit. So we suppose the profit p from a patient satisfies $p = \kappa$. Therefore, the expectation of the profit from curing a patient in need of the first diagnosis is $1/2$. Due to the limited diagnosis level of the CHC, the probability of misdiagnosis increases with the complexity of disease, and suppose the proportionality coefficient is 2. Therefore, if the upper bound of the complexity of disease that the CHC could handle is k (that is, if the complexity of a patient's disease exceeds k, the patient could not be treated in the CHC), the expectation of the CHC's profit from a patient is

$$\int_0^k (1-2\kappa)\kappa d\kappa = \frac{1}{2}k^2 - \frac{2}{3}k^3.$$

We consider the CHC and the GH form a healthcare alliance. In the alliance, the GH allocates a proportion of its capacity, $t, 0 \leq t \leq 1$, to facilitate the green channel for referral patients from the CHC. The profit generated from referral patients is shared by both healthcare institutions. In the first stage, we use a cooperative game framework to model the output of the negotiation in which the two healthcare institutions decide the fix proration rules that they will use to split the profits from referral patients, that is, β_1 $(0 < \beta_1 < 1)$ of profits generated by referral patients is collected by the GH and the rest is collected by the CHC. In the second stage, we model the operation of the alliance as a non-cooperative game in a decentralized network. In other words, due to the independence of the GH and the CHC, we can safely assume that once a fixed profit-sharing rule has been selected through the negotiation in the first stage, the GH decides the size of green channel t and the CHC chooses the level of diagnosis k simultaneously.

If the GH chooses to allocate t of its capacity to facilitate the green channel, this will influence the choice of the patients who require a first diagnosis. Because of the dedicated green channel t for referral patients, the probability that one patient could be treated by the GH decreases from $1/c$ to $(1-t)/c$. As a result, some of the patients in need of a first diagnosis may choose the CHC for their first diagnosis and the number of this part of patients is positively related to the size of green channel t. On one hand, the number of patients who change their choice definitely increases with the size of green channel t, that is, if the GH allocates more capacity to the green channel, more patients in need of the first diagnosis would choose the CHC. On the other hand, when there is no green channel, no one would switch to the CHC, and when the GH itself becomes a green channel, i.e. $t = 1$, no one will go to the GH for the first diagnosis. Therefore the number of patients in need of a first diagnosis whose choices change from the GH to the CHC $r = r(c,t)$ satisfies that $r(c,0) = 0$, $r(c,1) = c/2$ and $r(c,t)$ increases with c and t. For the simplicity, suppose there is a linear relation between c, t and $r = r(c,t)$, i.e. $r = ct/2$.

Therefore, in the healthcare alliance, the profit of the GH and the CHC is (the subscript 1, 2 represent the GH and the CHC respectively):

$$\begin{aligned}\pi_1 &= [\frac{c}{2}\cdot 1 + \left(\frac{c}{2}-\frac{c}{2}t\right)\cdot\frac{1}{2}]\frac{1-t}{\frac{c}{2}+(\frac{c}{2}-\frac{c}{2}t)} + \beta_1\frac{k+1}{2}\min\{(1-k)\frac{1+t}{2}c, t\} \\ &= \frac{(1-t)(3-t)}{2(2-t)} + \beta_1\frac{k+1}{2}\min\{(1-k)\frac{1+t}{2}c, t\},\end{aligned} \tag{1}$$

$$\begin{aligned}\pi_2 &= (\frac{c}{2}+\frac{c}{2}t)(\frac{1}{2}k^2-\frac{2}{3}k^3) + (1-\beta_1)\frac{k+1}{2}\min\{(1-k)\frac{1+t}{2}c, t\} \\ &= \frac{c(1+t)}{4}(k^2-\frac{4}{3}k^3) + (1-\beta_1)\frac{k+1}{2}\min\{(1-k)\frac{1+t}{2}c, t\}.\end{aligned} \tag{2}$$

The term $(1+k)/2$ is the expectation of profits from a referral patient. The term $(1-k)(1+t)c/2$ is the number of referral patients that the CHC intends to refer and $\min\{(1-k)(1+t)c/2, t\}$ is the number of referral patients successfully treated by the GH.

3 SIMULATION ANALYSES OF THE NASH EQUILIBRIUM

We start our analyses with the Nash equilibrium of the GH and the CHC in the second-stage game. Specifically, we analyze under which conditions the GH is willing to participate in the alliance and if the CHC is willing to take more effort to cure more patients in the alliance.

To solve the Nash equilibrium, we conduct computational experiments. We encode algorithms and analyze outputs in MATLAB. We first set up optimization functions of the GH, that is, for every revenue-sharing proportion, we solve the GH's best response, i.e. decision of the green channel's capacity, to every possible CHC's diagnosis bound, and do the same things for the CHC. Then we employ numerical analyses based on the above logic. In our numerical experiments, the CHC's capacity is in the set (1, 10), which is based on the fact that up to 2016, there were 28 thousand GHs and 928 thousand CHCs in China (From the report of National Health and Family Planning Commission of the People's Republic of China) and the number of beds in the GH is always several times of that in the CHC. From these experiments, we obtain the GH's and CHC's responses in the second stage for every possible revenue-sharing rule.

In the simulation of the Nash equilibrium for fixed proportion rates, we iterate proportion, i.e. β_1, from 0 to 1. For each β_1, we use $(t,k)=(0,0)$ as the initial alternative for Nash equilibrium. Then, we iterate t and k from 0 to 1, finding out the GH's and the CHC's profit respectively, and if both the GH's and the CHC's profit increase under a new pair (t,k), substitute this pair as the alternative Nash equilibrium. After the traversal operation, the final alternative is the Nash equilibrium (t,k) under the fixed proportion β_1. Denote the final alternative (t,k) as (t^*,k^*). Thus, the GH cannot obtain more profits by changing t^* if the CHC does not change k^* and the situation of the CHC is similar. In Section 4, we then investigate is there an optimal revenue-sharing rule which can lead the decentralized system achieving the same profits as a centralized one, that is, is it possible that the (t^*,k^*) is the same as the (t_0,k_0) which maximizes the alliance's total profits.

3.1 Simulation of the GH's Best Response

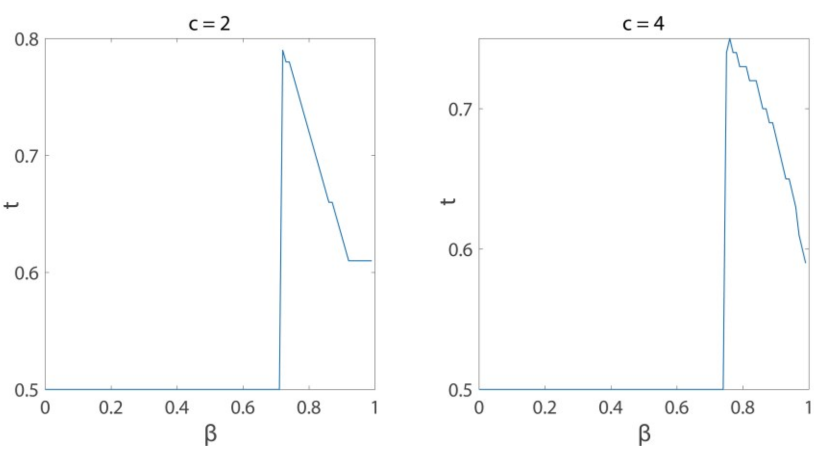

Figure 2: the GH's decision of capacity of the green channel under Nash equilibrium.

Given the revenue allocation and the CHC's referral rate, i.e. $\beta_1, 1-k$, the GH needs to decide its capacity allocation. The case $t=0$ indicates that the GH does not participate in this alliance, which means the alliance actually does not work. Under a fixed proration rate, if allocating the green channel could not improve the GH's profit, then the GH could decide to set $t=0$. Otherwise, joining the alliance could increase the GH's profit. Therefore, to make the alliance feasible, we should set proper proration rates for revenuing sharing to make sure the GH is willing to allocate green channel for referral patients.

The left and right figure in Figure 2 (see previous page) represent the decision of capacity of the green channel when the capacity of the CHC is 2 and 4 respectively. From these figures, it is obvious that for each capacity ratio, there exists a threshold of proportion β_1. Only if the β_1 negotiated in the first stage exceeds the threshold is the GH willing to cooperate with the CHC. Further, by comparing the two parts of Figure 2, we can find that the threshold increases with the CHC's capacity c, which implies that the larger the CHC is, the more profits of referral patients the GH wants.

3.2 Simulation of the CHC's Best Response

As we know, due to the probability of misdiagnosis, the higher bound of diagnosis does not necessarily lead to higher profits.

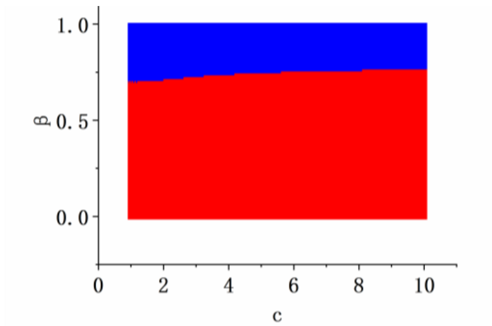

Figure 3: the conditions under which the CHC is willing to take more efforts to treat more patients.

Before joining the alliance, the optimal bound of diagnosis is $1/2$. By comparing k in equilibrium of decentralized decision and $1/2$, we investigate on the conditions in which the CHC is willing to take more effort to treat more patients. The blue areas in Figure 3 mean that the CHC will try harder to treat more patients under the specific combination of the capacity of the CHC c and the proration rate β_1 under the Nash Equilibrium. From Figure 3, we can find that for each capacity ratio, there exists a threshold of proportion β_1. Only if the β_1 negotiated in the first stage exceeds the threshold is the CHC willing to take more effects to treat more patients, the threshold increases with the CHC's capacity c, which implies that when the CHC is larger, fewer profits from referral patients are able to satisfy the CHC.

4 SIMULATION OF OPTIMAL REVENUE-SHARING RULES

In this section, we first analyze the feasibility of the revenue-sharing rules, that is, if both the GH and the CHC's revenue could be improved under the revenue-sharing proration, the rule is thought to be feasible. Then we explore the characteristics of the optimization problem of the whole alliance's profit and regard this as a benchmark of our model's efficiency. If the proportion rate can lead to an equilibrium (t, k) which is the same as the optimal (t^*, k^*) for the whole alliance, we think the revenue-sharing rule is efficient.

4.1 Feasibility of Revenue-Sharing Rules

As has been noted before, the GH could choose to secede the alliance by allocate no green channel, i.e. $t = 0$, if joining the alliance is not able to enhance its profits.

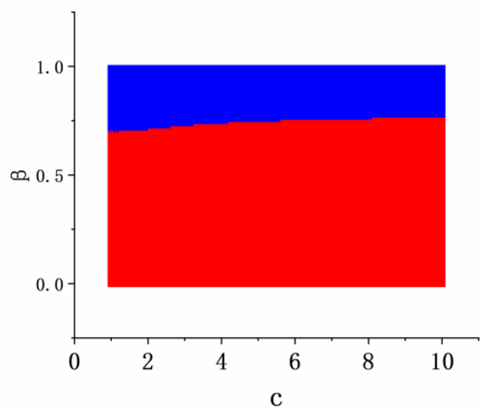

Figure 4: the conditions under which the GH is willing to cooperate with the CHC.

The blue area in Figure 4 represents the situation where the GH is willing to participate in the alliance with the CHC, while the read area represents the opposite. From Figure 4, we can find that for each capacity ratio, there exists a threshold of proportion β_1. Only if the β_1 negotiated in the first stage exceeds the threshold is the GH willing to cooperated with the CHC. Further, the threshold increases with the CHC's capacity c, which implies that the larger the CHC is, the more profits of referral patients the GH wants. Therefore, if the CHC could obtain enough revenue from referral patient, it is a good choice for the CHC to form an alliance with the GH. Also, comparing Figure 4 with Figure 3, it is obvious that as long as the GH takes part in the alliance, the CHC is willing to treat more patients.

As for the CHC, if the GH is willing to cooperate with it, it can obtain extra profits from two aspects. One is from the increased number of patients, and the other is from the revenue sharing in the referral patients. Therefore, participating in the alliance definitely does good to the CHC's profit.

4.2 Efficiency of Revenue-Sharing Rules

In this section, we explore the characteristics of the optimization problem of the whole alliance's profit. Then we compare these characteristics to the characteristics of the equilibrium of the decentralized system.

4.2.1 Simulation of the Centralized Case

The output of this problem could be the benchmark of the following analysis of decentralized decision. We can estimate the efficiency of the alliance by the difference between the total profits of the equilibrium of decentralized decision and the maximum of the alliance's profit. Optimization problem of the alliance's profit is:

$$\begin{aligned}(t^*,k^*) &= \arg\max_{0\le t,k\le 1} \pi = \arg\max_{0\le t,k\le 1}\ \pi_1+\pi_2 \\ &= \arg\max_{0\le t,k\le 1} \frac{(1-t)(3-t)}{2(2-t)} + \frac{c(t+1)}{4}\left(k^2-\frac{4}{3}k^3\right) + \frac{k+1}{2}\cdot\min\left\{\frac{c(1-k)}{2}(1+t),t\right\}\end{aligned} \tag{1}$$

The extremum problem for the alliance's profit is a higher order equation for which it is hard to find an analytical solution. Hence, we perform a numerical simulation to analyze the properties of this optimization. From numerical results, when the alliance's total profits achieve the maximum, the capacity of green channel always equal to the number of referral patients. Hence, the property of the optimal capacity t could reflect the characteristics of the optimization problem. Figure 5 shows the variation of the alliance's profit π with different sizes of the green channel t under different conditions.

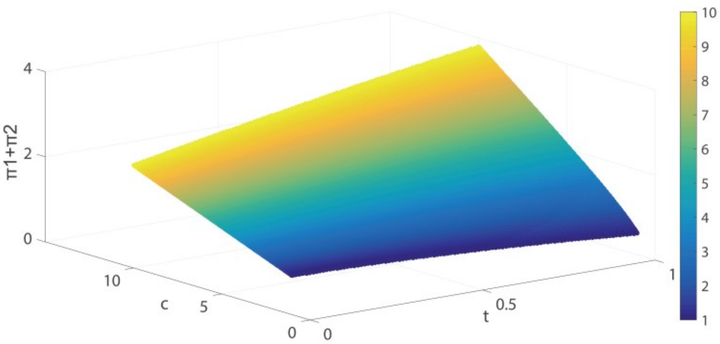

Figure 5: the variation of the alliance's profit π with different sizes of the green channel t under different conditions.

Figure 5 shows that the optimal size of green channel increases as the GH's capacity increases. When the GH's capacity reaches the threshold value, i.e. $c = \bar{c}$ the optimal size of green channel equals the total capacity, i.e. $t = 1$. This result indicates that when the ratio of the CHC's capacity to that of the GH is larger, the green channel is a better choice and when the CHC has enough capacity, the gatekeeper mode is the best choice for the profits of the whole alliance.

4.2.2 Simulation Comparison between the Equilibrium of Decentralized Decisions and the Output of Centralized Decision

To find out the optimal revenue sharing rule from the perspective of the whole alliance, we run numerical experiments to simulate the decision in the first stage. In the simulation of the second stage, we figure out the GH and CHC's total profit under Nash equilibrium under every fixed proportion. Then back to the simulation of the first stage, we iterate the revenue sharing proportion β_1 from 0 to 1, and calculate the total profit for every proportion under the Nash equilibrium. Finally, we choose the proportion which maximizes the alliance's total profit as the optimal revenue sharing rule.

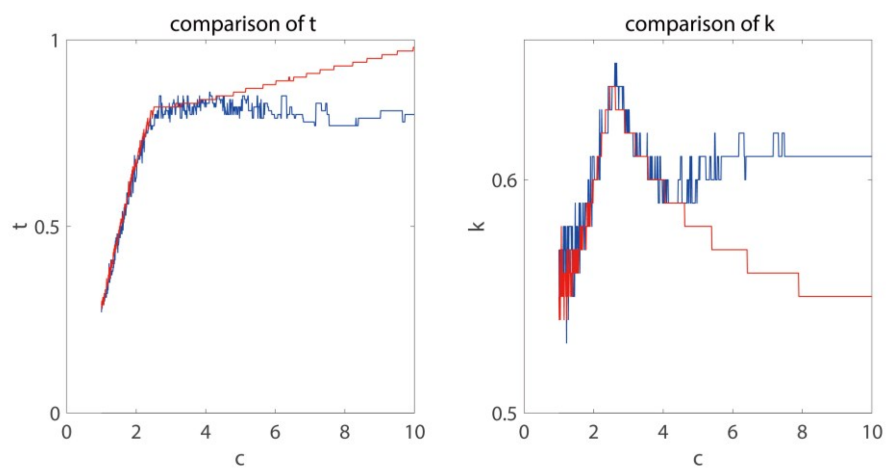

Figure 6: the comparison of the decision of the green channel's capacity and the CHC's diagnosis bound under the optimal revenue sharing rule and the centralized circumstance.

The blue and red lines in Figure 6 represent the circumstances under the optimal revenue sharing rule and the centralized circumstance respectively. From this comparison, we can see that the revenue sharing rule is virtually efficient when the capacity of the CHC is not too large, e.g. smaller than three times of the GH, where both the decision of the green channel's capacity and the CHC's diagnosis bound are very close to those under the centralized circumstance.

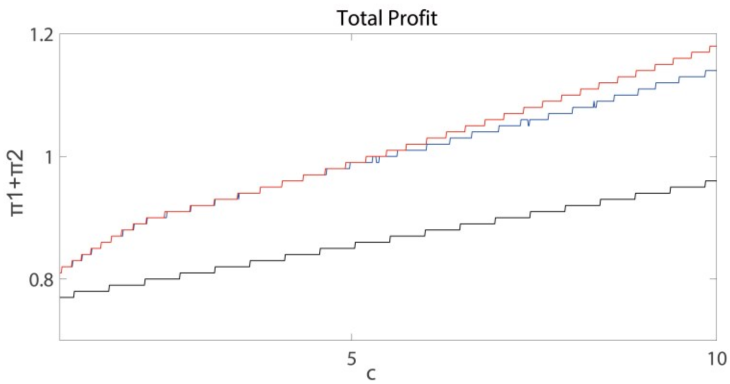

Figure 7: the comparison of total profit without the alliance, with the alliance under the optimal revenue sharing proportion, and under the centralized alliance.

The black, blue and red lines in Figure 7 represent the circumstances without the alliance, under the optimal revenue sharing rule and the centralized circumstance respectively. It is satisfactory that the alliance's total revenue increases at least 10% after forming the alliance. What's more, the superposition of the red line and the blue line in Figure 8 also verifies the efficiency of the alliance when the CHC's capacity is not too large.

5 CONCLUSION

We propose a two-stage game-theoretic approach to study the operations of the healthcare alliance and analyze the game through simulation. In the first-stage game, two providers negotiate fixed proration rates to share the revenue from referral patients. In the second-stage game, the GH makes the capacity allocation decision and the CHC decides referral rates to maximize their own revenues. We simulate the process of the game and analyze the non-cooperation game given a fixed revenue sharing contract and obtain the following results: 1) it is better for the GH to allocation less green channel than the number of referral patients when the CHC's capacity is not so huge. 2) The CHC is willing to take more effort to treat more patients under specific conditions. Further, by analyzing the characteristics of the centralized decision and compare it with the equilibrium, we obtain the conditions under which the alliance can be formed and when the decentralized system can achieve the same efficiency as a centralized one.

In the future work, we will extend our study with the consideration of the conflict and cooperation between the GH and the CHC under a more general model setting.

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