Research Article

Impacts of Payment Modes for Chronic Diseases by Diagnosis-Related Groups (DRGs) on Preventive Incentives of Medical Association

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Received 26 January 2022; Revised 12 March 2022; Accepted 14 March 2022; Published 5 May 2022

Academic Editor: Łukasz Jankowski

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To analyze prevention and treatment efforts under payment by DRGs, the optimal decision models of each participant are established. Prevention efforts of the community hospital and treatment efforts of the tertiary hospital under different payment modes have to be compared with the centralized decision-making of medical association. The results show some underpayment in both community and tertiary hospitals when the fees are charged according to the types of patients and the utility of the community hospital account in proportion to the total utility of the patients is a suitable value at the stage of treatment. Through DRGs, optimal prevention and treatment efforts under the centralized decision-making of medical association, and the maximization of social total utility are achieved.

1. Introduction

China is a country with the largest elderly population, which has reached about 260 million in 2021 and is expected to reach more than 450 million in 2050. The probability and mortality rate of chronic diseases in the elderly are on the rise, and the cost of treatment has brought heavy pressure to patients. To improve the quality of treatment of patients with chronic diseases and lessen medical costs, many hospitals tried a variety of methods to solve these problems. Among the more effective methods is encouraging patients to take preventive measures, such as modifying their medical insurance payment while yet in the prevention stage or before complications occur [1].

The traditional method of health payment is fee-or-service (FFS), in which patients are billed per medical service received from the hospital. This payment mode not only reduces the quality of care but also the responses of hospital over testing of patients [2], which increases the cost of patient care [3]. Therefore, medical insurance institutions try to design a new payment mode that would base on the total amount and treatment effect from the perspective of improving medical quality [4]. Payment by total amount means that the hospital first collects fixed medical fees from the patients, and then, the hospital bears all the medical expenses incurred by the patients. By encouraging hospital to improve the service rate, the total payment reduces the waiting time of patients and reduces the government’s subsidy to patients [5]. Although the payment by total amount has many advantages, the cost of treatment is directly proportional to the severity of patients’ disease. However, this payment mode cannot reasonably compensate the expenditure and mobilize the enthusiasm of the hospital [6]. Payment by total amount and payment by treatment effect have different impacts on the treatment of chronic patients [7]. Scholars mainly carried out empirical analysis and case studies. Empirical analysis found that payment by total amount reduces the cost of patients with chronic diseases [8], while payment by treatment effect cannot effectively improve the symptoms of patients with diabetes [9]. Case studies have found that payment based on treatment results improves the quality of care for healthcare workers [10]. Although both payments by total amount and treatment effect can improve the enthusiasm of hospital, it
also allowed the hospital to choose patients with mild disease for treatment or reject patients with severe disease that may incur higher medical costs [11].

Payment by DRGs is a kind of new measure of the efficiency of medical service quality based on payment. The payment is essentially a case mix classification scheme, very suitable for application in slow disease management, namely, according to age, disease diagnosis, complications, disease severity, and resource consumption. It is a system for managing patients into several diagnostic groups [12]. From the perspective of hospital financial risk, some scholars analyzed the DRGs [13] and found that the risk transfer mode of DRGs effectively reduces the financial risk of hospital [14]. Over the past two decades, more than 20 countries have implemented cluster payment strategies based on disease diagnosis. In order to expand the DRG framework, some countries have grouped patients into multiple groups: the severe DRG-related grouping in the United States, the DRG-related grouping in Germany, the mixed-case grouping in Canada, the healthcare resource groups in the United Kingdom, and the refined DRG-related grouping in Australia [15]. In June 2020, China issued the notice on printing and distributing the List of National Pilot cities for payment by DRGs. In 2021, the 30 national pilot cities were required to start actual charging by the DRGs. Compared with traditional payment modes, the DRGs effectively reduce hospitalization costs [16] and improves the accuracy of estimated medical costs [17]. At present, 60.8% of hospitals have already adopted DRG payment or are piloting DRG payment in China. Under the impact of DRGs, drug costs dropped the most, by 37.82% compared to 2021.

Existing literature mainly analyzes the impact of payment modes on patients with chronic diseases through empirical analysis and case studies. Based on the case study method, it is found that DRGs improve the service quality of medical staff [14]. Some scholars proposed DRGs for patients with chronic diseases and analyzed them from the perspective of financial risk of hospitals [16]. After research, this risk transfer method can effectively reduce the financial risk of hospitals [17]. Few literature studies analyze the impact of payment modes by DRGs on medical institutions and patients by constructing quantitative models. The payment model is between a requester and a provider (similar to the community hospital and tertiary hospital in our model). That coordinates preventive work by the requester and follow-up work by the provider to ensure better health care [18]. In contrast, we focus on the payee to the medical association under different payment models, not payment between the requester and provider.

Patients with chronic diseases are categorized into mild and severe chronic diseases. Patients with mild chronic diseases are given preventive interventions by the community hospital. If the prevention fails at the community hospital level, patients with severe chronic diseases will be transferred to and directly treated or queue up for treatment at the tertiary hospital. Payment through the DRGs will encourage the community hospital to make preventive efforts to reduce the probability of complications in mild patients and reduce their time patients wait for treatment outside of the tertiary hospital for appointments. From the perspective of operational management, this article discusses how payment mode by the DRGs promotes the division of labor and cooperation between community hospital and tertiary hospital.

Medical insurance institutions are responsible for the collection, management, and payment of medical insurance fees. Along with medical insurance institutions, the community hospital and tertiary hospital jointly provide medical services for patients. It is assumed that the medical expenses for patients with medical insurance are entirely borne by the medical insurance institutions. It is believed, however, that the medical association of common management can deteriorate patient’s health. Because healthcare institutions provide different ways of payment for medical association and thus will have a different effect of medical association. Therefore, this study looks into the kind of healthcare payment mode that can achieve synergy to produce their optimal social utility. It is assumed that the health insurance institutions, the community hospital, and tertiary hospital are risk-neutral.

2. Problem Description and Symbolic Definition

According to the severity of chronic disease, patients can be divided into mild and severe patients. Patients in this healthcare system go through a two-stage process. First, patients with mild symptoms are treated in the community hospital and only transferred to the tertiary hospital for treatment after complications occurred. Second, mild patients with complications are lined up for treatment along with severe patients who go directly to the tertiary hospital. Figure 1 shows the relationship between the community hospital, the tertiary hospital, and patients.

We assume $i$ represents the patient type, where $i = 1$ represents a mild patient and $i = 2$ represents a severe patient. Patients with mild diseases are prevented in the community hospital, where prevention efforts are made $x$. Prevention efforts mainly include patient education, patient medication monitoring, and implementation of chronic disease management plans. The main purpose of community hospital is to distinguish patients’ health status and prevent complications in mild cases. Additional medical costs will be incurred if mild patients are transferred to the tertiary hospital.

The cost of the community hospitalization consists of two parts—one is the fixed cost $C_2$ (drug cost, equipment use cost, etc.) and the other is the efforts cost $M_i(x)$, where $M_i(x)$ is a convex increasing in $x$, function of $M'_i(x) > 0$ and $M''_i(x) > 0$. We assume that the total number of patients is $n$, and the proportion of mild patients to the total number of patients is $\theta$ ($0 < \theta < 1$). If a mild patient develops complications and becomes a severe patient, the community hospital will transfer the severe patient to the tertiary hospital for treatment. Therefore, the prevention efforts of the community hospital will affect the probability of the patient being transferred $\lambda(x)$, where $0 < \lambda(x) < 1$, and $\lambda'(x)$ is a decreasing function of $x$, $\lambda'(x) < 0$. 
The medical association aims at maximizing its utility. Under the method of utility, the community hospital has a lower cost level on prevention efforts for mild patients in order to maximize their own utility and reduce costs. The tertiary hospital has treatment efforts for severe patients, resulting in corresponding treatment costs and reducing the waiting time of patients in the tertiary hospital, thereby reducing medical costs. Under payment mode by the DRGs, the medical association charges different fees for patients with mild or severe disease. Stimulated by charging fees for patients with mild diseases, the community hospital makes prevention efforts for patients with mild diseases, which resulted in a corresponding cost of prevention efforts, reducing the probability of referral to the tertiary hospital, and reducing the cost and waiting time for patients in the tertiary hospital due to complications. Mild patients with complications will queue up with serve patients for treatment in tertiary hospitals. Under the combined stimulation of charging fees for mild and severe patients, the tertiary hospital has treatment efforts for patients at corresponding treatment effort costs and that also reduced the waiting time of patients in the tertiary hospital. Therefore, based on the goals of the community and tertiary hospitals, it is necessary to make decisions on the optimal prevention efforts at the community hospital level and the optimal treatment efforts at the tertiary hospital level. We compare the optimal efforts under the centralized decision of medical association by the FFS and by the DRGs, so as to provide decision-making suggestions for medical insurance institutions to choose payment modes.

Assumption 1. We assume the functions $M_L(x)$, $S(x)$, $M_C(y)$, $W(x, y)$, and the parameter $\beta$ satisfy the following inequality:

$$S(x) \left( W_{yy}(x, y) \beta + M_C''(y) \right) \cdot \left[ n \theta M_L''(x) + \beta (S'(x)W_{yy}(x, y) + S(x)W_{xx}(x, y)) \right] - \left[ S'(x) \left( W_{yy}(x, y) \beta + M_C''(y) \right) - \beta S(x)W_{xy}(x, y) \right]^2 > 0. \tag{1}$$

Assumption 1 implies that the optimization problems we consider are concave. Intuitively, there are results in terms of the effectiveness of prevention efforts of the community hospital and treatment efforts of the tertiary hospital.

3. Decision Models of Prevention and Treatment Efforts under Different Payment Modes

3.1. Optimal Decision under Centralized Decision of Medical Association. The utility of medical association is to place an order and determine a standard to evaluate prevention and treatment efforts under different payment modes. It also aims at understanding the optimal level of effort of the target, and the medical association is assumed to be the sole decision-maker with the goal of maximizing its utility.
\[ \pi(x, y) = -n\theta(C_1 + M_L(x)) - S(x)(C_S + M_S(y) + \beta W(x, y)). \] (2)

In order to maximize the utility of medical association centralized decision, the utility of medical association centralized decision is omitted, which is not affected by payment mode.

**Lemma 1.** \( \pi(x, y) \) is a joint concave function of \((x, y)\).

The proof of Lemma 1 is in the Appendix. \((x^*, y^*)\) maximizes the utility of medical association, which is obtained by the following conditions:

\[
\begin{align*}
\theta M_L'(x) + S'(x)(C_S + M_S(y) + \beta W(x, y)) \\
+ \beta S(x)W_y'(x, y) = 0, \quad (3)
\end{align*}
\]

\[ W_y'(x, y)\beta + M_S(y) = 0. \]

**Lemma 2.** \( x^* \) are increasing in \(C_S \) and increasing in \( \beta \), \( y^* \) are increasing in \( \beta \) and independent of \( C_S \).

The proof of Lemma 2 is in the Appendix. Lemma 2 indicates that when the standard treatment cost of the tertiary hospital increases, the community hospital reduces the probability of patients being transferred to the tertiary hospital for treatment by increasing prevention efforts, thus reducing the cost of medical association. Treatment efforts in the tertiary hospital are not affected by standard care costs in the tertiary hospital. When the cost per unit time increases due to delayed treatment in the tertiary hospital, the community hospital reduces the waiting time for patients by making an appointment in the tertiary hospital and increases prevention efforts. The tertiary hospital reduces the cost of medical association by increasing treatment efforts.

### 3.2. Optimal Decision under Utility.

According to utility, if a mild patient receives prevention in the community hospital, the cost that the medical insurance institution should pay to the community hospital is \( C_1(x) \). Severe cases are treated in the tertiary hospital, and the cost that the health insurance institution has to pay to the community hospital is \( C_2(y) \). The utility of the community hospital and tertiary hospital is, respectively,

\[
\begin{align*}
\pi_1(x) &= n\theta(C_1(x) - C_L - M_L(x)), \\
\pi_2(y) &= S(x)(C_2(y) - C_S - M_S(y) - \beta W(x, y)). \quad (4)
\end{align*}
\]

In order to ensure the nonnegative utility of the community hospital and tertiary hospital, the fees \( C_1(x) \) and \( C_2(y) \) charged by the community hospital should be satisfied:

\[
\begin{align*}
C_1(x) &\geq C_L + M_L(x), \\
C_2(y) &\geq C_S + M_S(y) + \beta W(x, y). \quad (5)
\end{align*}
\]

Under the mode of utility, the community hospital and tertiary hospital aim at maximizing their respective utility. Prevention efforts at the community hospital \( x^{FFS} \) and treatment efforts at the tertiary hospital \( y^{FFS} \) are shown as follows:

\[
\begin{align*}
n\theta(C_1'(x) - M_L'(x)) = 0, \\
S(x)(C_2'(y) - M_S'(y) - \beta W_y'(x, y)) = 0. \quad (6)
\end{align*}
\]

**Lemma 3.** \( y^{FFS} \) is decreasing in \( \beta \).

The proof of Lemma 3 in the Appendix. Lemma 3 indicates that under the payment mode of FFS, when the cost per unit time increases due to delayed treatment by the tertiary hospital, the tertiary hospital reduces their own cost by reducing treatment efforts in order to maximize their own utility.

### 3.3. Optimal Decision-Making under the DRGs.

As chronic disease patients are divided into two groups: mild chronic disease and severe chronic disease. It is assumed that the cost of prevention in the tertiary hospital for mild patients is \( B_1 \), and the cost of treatment in the tertiary hospital for severe patients without prevention in the community hospital is \( B_2 \). As the community hospital prevention efforts and the tertiary hospital treatment efforts are assessed under different payment modes, it is important to ensure that the DRGs are equivalent to the utility. The utility of the community hospital consists of two parts: one is the successful treatment of mild and chronic patients, and the other is the proportion of the total utility of patients in the treatment stage, which is \( f \). The proportion of the utility of the tertiary hospital to the total utility of patients in the treatment phase is \( 1 - f \).

The utility of the community hospital and tertiary hospital is, respectively,

\[
\begin{align*}
\pi_1(x, y) &= n\theta(1 - \lambda(x))(B_1 - C_L - M_L(x)) \\
&\quad + f [n\theta\lambda(x)(B_1 - C_L - M_L(x)) + n(1 - \theta)B_2] \\
&\quad - S(x)(C_S + M_S(y) + \beta W(x, y)), \\
\pi_2(x, y) &= (1 - f)(n\theta\lambda(x)(B_1 - C_L - M_L(x)) + n(1 - \theta)B_2) \\
&\quad - S(x)(C_S + M_S(y) + \beta W(x, y)). \quad (7)
\end{align*}
\]

In order to ensure the nonnegative utility of the community hospital and tertiary hospital, \( B_1 \) and \( B_2 \) should be satisfied:

\[
\begin{align*}
n\theta\lambda(x)B_1 + n(1 - \theta)B_2 &\geq S(x)(C_S + M_S(y) + \beta W(x, y)) \\
&\quad + n\theta\lambda(x)(C_L + M_L(x)). \quad (8)
\end{align*}
\]

Under the DRGs, the community hospital and tertiary hospital aim at achieving the maximum utility. Prevention efforts \( x^{DRG} \) in the community hospital and treatment efforts \( y^{DRG} \) in the tertiary hospital are shown as follows:

\[
\begin{align*}
n\theta(1 - \lambda(x) + f\lambda(x))M_L'(x) \\
&\quad + n\theta\lambda'(x)(1 - f)(B_1 - C_L - M_L(x)) \\
&\quad + fS'(x)(C_S + M_S(y) + \beta W(x, y)) = 0, \\
(1 - f)S(x)(M_S'(y) + \beta W_y'(x, y)) = 0. \quad (9)
\end{align*}
\]
Lemma 4. $x^{\text{DRG}}$ is increasing in $C_5$ and $\beta$. $y^{\text{DRG}}$ is increasing in $\beta$.

The proof of Lemma 4 is in the Appendix. Lemma 4 shows the payment according to the DRGs, when each unit of time due to delay in the tertiary hospital treatment cost increases, by strengthening prevention efforts in the community hospital and treatment efforts in the tertiary hospital, the waiting time for patients to make an appointment in the tertiary hospital can be reduced, so as to reduce the cost of medical association. When the standard treatment cost of the tertiary hospital increases, the community hospital reduces the probability of patients being transferred to the tertiary hospital for treatment by increasing prevention efforts, thus reducing the cost of medical association.

Lemma 5. $x^{\text{DRG}}$ is increasing in $f$ and $B_1$.

The proof of Lemma 5 is in the Appendix. Lemma 5 indicates that when the proportion of the utility of the community hospital to the utility of patients in the treatment stage increases according to the DRGs, the community hospital makes preventive efforts to reduce the waiting time of patients to make an appointment to the tertiary hospital for treatment, thus increasing the utility in the treatment stage. As the total charge fee for mild patients increases, the community hospital makes preventive efforts to reduce the cost of transferring patients from the community hospital to the tertiary hospital, thus increasing their own utility.

4. Coordination Strategy Payment Mode Based on the DRGs

The centralized decision of medical association can be used as a benchmark to compare different payment modes, and the utility of medical association can be maximized by coordinating payment modes.

Proposition 1. $x^{\text{FFS}} < x^*$, $y^{\text{FFS}} \geq y^*$.

The proof of Proposition 1 is in the Appendix. Proposition 1 shows that treatment efforts of the tertiary hospital under the FFS are always not less than optimal treatment efforts under the centralized decision of medical association. However, prevention efforts of the community hospital are always less than optimal prevention efforts under the centralized decision of medical association. Since the probability of patients transferring from the community hospital to the tertiary hospital for treatment does not affect the utility of the community hospital, the utility does not stimulate the community hospital to make more prevention efforts to prevent patients. The prevention efforts of the community hospital under the utility cannot reach the optimal prevention efforts under the centralized decision of medical association through the coordination of health insurance institutions.

Proposition 2. If $n\theta\lambda(a^{\text{FFS}})B_1 + n(1-\theta)B_2 \geq S(a^{\text{FFS}})(C_5 + M_5(S(y^{\text{FFS}}) + \beta W(x^*, y^{\text{FFS}})) + n\theta\lambda (x^{\text{FFS}})(C_1 + M_1(x^{\text{FFS}})))$, then $x^{\text{DRG}} \geq x^*$, $y^{\text{DRG}} \geq y^*$.

The proof of Proposition 2 is in the Appendix. Proposition 2 shows that in order to maximize their own utility, the community hospital has to improve their prevention efforts. To reduce patient probability to be transferred the tertiary hospital, waiting time for patient appointments has to be reduced. The prevention efforts of the community hospital are always greater than those of community hospital under centralized decision, which shows optimal prevention efforts. In order to maximize their own utility, the tertiary hospital reduces the waiting time for patients to make an appointment in the tertiary hospital by increasing their treatment efforts, and treatment efforts of the tertiary hospital are no less than those under the centralized decision of medical association. The medical insurance institutions coordinate the fees paid to different types of patients in the medical association and the proportion of the utility of the community hospital in the total utility of patients in the treatment stage. The community hospital and tertiary hospital in the medical association adjust their prevention and treatment efforts according to their own utility. Therefore, prevention efforts of the community hospital and treatment efforts of the tertiary hospital under the DRGs achieve the optimal prevention efforts and treatment efforts under the centralized decision of medical association.

According to Proposition 2, it can be seen that the cost $B_1$ of prevention in the community hospital for mild patients, the cost $B_2$ of direct transfer to the tertiary hospital for treatment for severe patients without the community hospital prevention, and the proportion $f$ of the utility of community hospital in the total utility of patients in the treatment stage are under an appropriate value. The prevention efforts of the community hospital and the treatment efforts of the tertiary hospital achieve the optimal prevention efforts under the centralized decision of medical association.

The proof of Theorem 1 is in the Appendix.

Theorem 1. As $F_1 = S'(x^*)(C_5 + M_5(y^*) + \beta W(x^*, y^*) + \beta S(x^*)W'_x(x^*, y^*), F_2 = -S'(x^*)(C_5 + M_5(y^*) + \beta W(x^*, y^*) - n\theta\lambda'((x^*)(C_1 + M_1(x^*))$, $F_3 = S'(x^*)(C_5 + M_5(y^*) + \beta W(x^*, y^*) - n\theta\lambda'((x^*)(C_1 + M_1(x^*)) - \beta S(x^*)W'_x(x^*, y^*) - n\theta\lambda(M(x^*))$, If $B_1 = F_1 + F_3 + \sqrt{F_1 + F_3} - 2F_1F_3/F_3 - 2n\theta\lambda'(x^*), f = F_3 - F_1 - \sqrt{F_1 + F_3}/4F_1F_3/F_3 - F_1 - F_3 - \sqrt{F_1 + F_3} - 4F_1F_3/F_3 - 2F_3x - 2n\theta\lambda'(x^*)M'(x^*)$ and $B_2 = S(x^*)(C_5 + M_5(y^*) + \beta W(x^*, y^*) + n\theta\lambda'(x^*)(C_1 + M_1(x^*)) / n(1-\theta) - \lambda(x^*) [F_1 + F_3 + \sqrt{F_1 + F_3} - 4F_1F_3] / 2\lambda(x^*)$, medical insurance institutions achieve the optimal prevention and treatment efforts under the centralized decision of medical association, by coordinating the expenses of mild and severe patients paid according to the DRGs and the proportion of the utility of the community hospital in the total utility of patients in the treatment stage.

5. Patient Utility and Total Social Utility

5.1. Patient Utility. The effect of medicare payment modes on health outcomes was modeled using QALYs as a measure of health [19], comparing QALYs with financial outcomes through the willingness to pay conversion coefficient.

We assume the initial health status of patient $i$ is $q_i^0$, where $q_i^0$ represents the monetary value of health capital
Since the total social utility function increases the utility part of patients compared with the utility function of the centralized decision of medical combination, the prevention and treatment efforts aiming at the maximization of total social utility are not less than the optimal prevention and treatment efforts under the centralized decision of medical association.

**Corollary 2.** As \( F_4 = -an\theta_1^2l' (x^5) - bn(1 - \theta)\theta_1^2l' (x^5) / y^s - n g(x) + \beta W(x, y^s) + \beta S(x^s) W'(x^s, y^s) \), \( F_5 = -S' (x^s)(C_S + M_S(y) + \beta W(x, y^s)) - n \theta_1 l' (x^5)(C_L + M_L(x^s)), \) \( F_6 = S'(x^s)(C_S + M_S(y^s) + \beta W(x^5, y^s)) - n \theta_1 l' (x^5)(C_L + M_L(x^s)) - \beta S(x^s) W'(x^s, y^s) - n \theta_1 l (x^5) M_L(x^5) \). If \( B_2 = F_4 + F_6 + \sqrt{(F_4 + F_6)^2 - 4F_4F_6}/2n\theta_1 l' (x^5), \) then \( B_2 = S(x^s)(C_S + M_S(y^s) + \beta W(x^5, y^s)) + n \theta_1 l (x^5)(C_L + M_L(x^s))/n(1 - \theta) - \lambda (x^5)[F_4 + F_6 + \sqrt{(F_4 + F_6)^2 - 4F_4F_6}/2l' (x^5)], \) medical insurance institutions achieve the optimal prevention and treatment efforts under the maximization of the total social utility, by coordinating the expenses of mild and severe patients paid according to the DRGs and the proportion of the utility of the community hospital in the total utility of patients in the treatment stage.

### 6. Example Analysis

This section uses numerical examples to analyze the following four aspects: (1) the impact of patients’ waiting time for appointment to the tertiary hospital on prevention efforts and treatment efforts under different payment modes; (2) the impact of prevention costs of mild patients in the community hospital on prevention efforts under different payment modes; (3) the impact of treatment efforts under different payment modes on the cost of serious patients being directly transferred to the tertiary hospital without community hospital prevention; and (4) after the coordination of payment modes based on disease diagnosis, the prevention efforts of the community hospital and the treatment efforts of the tertiary hospital reached the optimal under the centralized decision-making of medical association and the maximization of total social utility, respectively.

According to the assumption given in this article, the abstract function can be expressed concretely. The probability of patients’ transfer from the community hospital to the tertiary hospital is \( \lambda (x) = 1 - x \). The average arrival rate of patients in tertiary hospital is \( \lambda (x) = \theta_1 (x) + 1 - \theta \). The total number of patients in the treatment stage is \( x = n\theta_1 (1 - x) + n(1 - \theta) \). The cost received by community hospital is \( C_1(x) = k_1 x + C_1 \). The cost received by the tertiary hospital is \( C_2(y) = k_2 y + C_2 \). The cost of prevention efforts of the community hospital is \( M_1(x) = 1/2k_1 x^2, \) \( M_S(y) = 1/2k_2 y^2 \), waiting time \( W(x, y) = 1/y - ng(x) \). The expression of the abstract function of the assumption satisfies Assumption 1.
We set the parameter values $C_S = 12000$, $C_5 = 40000$, $C_1 = 15000$, $C_2 = 45000$, $n = 100$, $\beta = 0.5$, $k_L = 20$, $k_1 = 2$, $k_2 = 2$, $a = 0.2$, $b = 1$.

(1) We set $f = 0.3$, $B_1 = 15000$, $B_2 = 42000$, $\beta$ effect on prevention efforts and treatment efforts under centralized decision of FFS and medical association.

Figure 2 shows that with the increase in the waiting time for patients to make an appointment in the tertiary hospital, the prevention efforts under FFS are always smaller than those under the centralized decision of medical association.

Figure 3 shows that when $1 \leq \beta < 2.2$, treatment efforts under FFS are greater than those under the centralized decision of medical combination. When $\beta = 2.2$, the treatment efforts under FFS are equal to those under the centralized decision of medical association. When $\beta > 2.2$, the treatment efforts under FFS are smaller than those under the centralized decision of medical association.

(2) The effect of $f = 0.3$, $B_1 = 15000$, $B_2 = 42000$, $\beta$ on prevention and treatment efforts under the DRGs and the centralized decision of medical association.

Figure 4 shows that with the increase in the waiting time for patients to make an appointment in the tertiary hospital, the prevention efforts under the DRGs are greater than those under the centralized decision of medical association.

Figure 5 shows that when $1 \leq \beta < 4.8$, the treatment effort under the DRGs is greater than that under the centralized decision of medical association. When $\beta = 4.8$, the treatment efforts under the DRGs are equal to those under the centralized decision of the medical association. When $\beta > 4.8$, the treatment efforts under the DRGs are smaller than those under the centralized decision of medical association.

(3) The effect of $f = 0.3$, $\beta = 1$, $B_1$ on prevention efforts under the DRGs and the centralized decision-making by medical association.

Figure 6 shows that when $10000 \leq B_1 < 12000$, the prevention efforts under the DRGs are smaller than those under the centralized decision of medical association. When $B_1 = 12000$, the prevention efforts under the DRGs are equal to those under the centralized decision of medical association. When $B_1 > 12000$, the prevention efforts under the DRGs are greater than those under the centralized decision of medical association.
(4) We set \( \beta = 1, d_1^0 = 355000, d_2^0 = 350000 \). After coordinating the cost of mild patients and the proportion of community hospital’s utility in the treatment stage, the prevention efforts of community hospital and treatment efforts of the tertiary hospital reach the optimal prevention efforts and treatment efforts under the centralized decision-making of medical association and the maximization of total social utility, respectively.

Figure 7 shows that when \( f = 0.5, B_1 = 17017 \) of the DRGs, the medical insurance institutions coordinate the cost of minor patients, which is \( B_1^* = 15175 \), and the utility proportion of the community hospital in the treatment stage is \( f^* = 0.55 \). The prevention efforts of the community hospital according to the DRGs reach the optimal prevention efforts under the total social utility. After calculation, when \( B_2 \geq 41625 \), the utility of tertiary hospitals is guaranteed to be nonnegative. Under the same prevention effort, the treatment effort based on the DRGs is equal to the treatment effort under the centralized decision of medical
association. Therefore, by coordinating the costs of different types of patients and the proportion of the utility of the community hospital in the treatment stage, the medical insurance institutions achieve the optimal prevention and treatment efforts under the centralized decision of medical association by paying the prevention and treatment efforts according to the DRGs.

Figure 8 shows that when \( f = 0.75, B_1 = 16742 \) of payment mode according to the DRGs, medical insurance institutions coordinate the cost of minor patients, which is \( B_1' = 14962 \), and the utility proportion of the community hospital in the treatment stage is \( f' = 0.71 \). The prevention efforts of the community hospital under the DRGs achieve the optimal prevention efforts under the total social utility. After calculation, when \( B_1 \geq 52035 \), the utility of the tertiary hospital is guaranteed to be nonnegative, and the treatment efforts based on the DRGs are equal to those under the total utility of society under the same prevention efforts. Therefore, by coordinating the costs of the different types of patients and the proportion of the utility of the community hospital in the treatment stage, the medical insurance institutions achieve the optimal prevention and treatment efforts under the maximization of the total utility of the society by paying the prevention and treatment efforts according to the DRGs. A summary of key results is provided in Table 1.

### 7. Conclusions and Prospects

This article studies the mode of payment in patients with chronic diseases, taking into account the problem of referral between the community hospital and tertiary hospital. It considers the utility of community and tertiary hospitals through its prevention efforts under the centralized decision-making under the DRGs and on its coordination to achieve the optimal prevention efforts. By coordinating the cost of different types of patients and the proportion of utility of the community hospital in the treatment stage, the optimal prevention and treatment efforts were reached under the centralized decision of medical association. This article analyzes the patients’ utility, and utility of the community hospital as well as the utility of the tertiary hospital, through the coordination costs of different types of patients and the utility of the community hospital in the treatment of stage, the proportion of DRGs of the community hospital prevention efforts, and on how the tertiary hospital treatment achieves social total utility maximization under the optimal prevention and treatment efforts. We focus on the payer to the medical association under different payment models, not payment between the requester and provider. When fees are based on patient type and the utility of community hospital is high at the stage of treatment, the research results will help him to adopt the DRG payment for chronic diseases. From the perspective of the healthcare payer, the research results will help him to adopt the DRG payment for chronic diseases. In making the efficient cooperation between the community hospital and the tertiary hospital, patients from the community hospital will likely reduce their probability of receiving delayed appropriate treatment in the tertiary hospital.

In this article, we have some limitations. First, we have not considered the medical association is risk-averse, and under this assumption, the DRGs have higher referral rates from the community hospital to the tertiary hospital, higher utility of the community hospital, and the tertiary hospital. Second, the continuous distribution of patients’ health status is not considered. In the future work, the study on the DRGs of patients with chronic diseases will be improved, which is more consistent with the actual situation.

### Appendix

The Proof of Lemma 1. Under centralized decision of the medical association, the first and second derivatives of \( \pi(x, y) \) with respect to \( x \) and \( y \) are

\[
\frac{\partial \pi(x, y)}{\partial x} = -n \theta M'_1(x) - S'(x)(C_S + M_S(y) + \beta W(x, y)) - \beta S(x)W'_x(x, y),
\]

\[
\frac{\partial^2 \pi(x, y)}{\partial x^2} = -n \theta M''_1(x) - S''(x)(C_S + M_S(y) + \beta W(x, y)) - \beta (S'(x)W'_x(x, y) + S(x)W''_x(x, y)),
\]

\[
\frac{\partial \pi(x, y)}{\partial y} = -S(x)(W'_y(x, y) + \beta M'_1(y)),
\]

\[
\frac{\partial^2 \pi(x, y)}{\partial y^2} = -S(x)(W''_y(x, y) + \beta M''_1(y)),
\]

\[
\frac{\partial^2 \pi(x, y)}{\partial x \partial y} = -S'(x)(W'_{xy}(x, y) + \beta M'_1(y)) + \beta S(x)W''_{xy}(x, y),
\]

(A.1)
where \( \Delta_1 = S(x)(W_{xy}''(x,y)\beta + M_S''(y)) \) \[ n \theta M_L''(x) + S''(x) \]
\((C_S + M_S(y) + \beta W(x,y)) + \beta S(x)W''_x(x,y) + S(x)W''_x(x,y) \) \[ - (S'_x(x)W'_x(x,y)\beta + M_L'(y) - \beta S(x)W'_x(x,y,y)) \]². It can be seen from Assumption 1 that \( \Delta_1 > 0 \), \( \pi(x,y) \) is a joint concave function with respect to \( (x,y) \).

The Proof of Lemma 2. \( \pi(x^*, y^*) \) is obtained from the following equation:
\[ n \theta M_L''(x^*) + S''(x^*)(C_S + M_S(y^*) + \beta W(x^*, y^*)) \]
\[ + \beta S(x^*)W_x'(x^*, y^*) + \beta S(x^*)W''_x(x^*, y^*) \]
\[ = -S'(x^*). \]  
\[ (A.2) \]
\[ W'_x(x^*, y^*)\beta + M_L'(y^*) = 0. \]  
\[ (A.3) \]

The derivative of \( x^* \) with respect to \( C_S \) in equation (A.1) is
\[ \frac{dx^*}{dC_S} = \frac{d}{dC_S} \left[ n \theta M_L''(x^*) + S''(x^*)(C_S + M_S(y^*) + \beta W(x^*, y^*)) \right] \]
\[ + \beta S(x^*)W'_x(x^*, y^*) + \beta S(x^*)W''_x(x^*, y^*) \]
\[ = -S'(x^*)W(x^*, y^*) - S(x^*)W'_x(x^*, y^*). \]  
\[ (A.4) \]

From the assumptions, thus, \( dx^*/dC_S > 0 \).  
The derivative of \( x^* \) with respect to \( \beta \) in equation (A.1) is
\[ \frac{dx^*}{d\beta} = \frac{d}{d\beta} \left[ n \theta M_L''(x^*) + S''(x^*)(C_S + M_S(y^*) + \beta W(x^*, y^*)) \right] \]
\[ + S'(x^*)W'_x(x^*, y^*) + \beta S(x^*)W''_x(x^*, y^*) \]
\[ + \beta S(x^*)W''_x(x^*, y^*) \]
\[ = -S'(x^*)W(x^*, y^*) - S(x^*)W'_x(x^*, y^*). \]  
\[ (A.5) \]

The derivative of \( y^* \) with respect to \( \beta \) is
\[ (W''_y(x^*, y^*)\beta + M_S''(y^*))dy^*/d\beta = -W''_y(x^*, y^*). \]
Thus, \( dy^*/d\beta < 0 \).

The Proof of Lemma 3. \( \gamma^{FFS} \) is obtained from the following equation:
\[ C_S'(y^{FFS}) - M_S'(y^{FFS}) - \beta W'_y(x^{FFS}, y^{FFS}) = 0. \]  
\[ (A.6) \]

The derivative of \( \gamma^{FFS} \) with respect to \( \beta \) in equation (A.3) is
\[ \frac{d\gamma^{FFS}}{d\beta} = \frac{d}{d\beta} \left[ C_S'(y^{FFS}) - M_S'(y^{FFS}) - \beta W'_y(x^{FFS}, y^{FFS}) \right] \]
\[ = W'_y(x^{FFS}, y^{FFS}). \]
From the assumptions, thus, \( d\gamma^{FFS}/d\beta < 0 \).

The Proof of Lemma 4. \( \pi(x^{DRG}, y^{DRG}) \) is obtained from the following equation:
\[ n \theta(1 - \lambda(x^{DRG}) + fM(x^{DRG}))M'_L(x^{DRG}) \]
\[ + n \theta(1 - f)(B_1 - C_L - M_L(x^{DRG})) \]
\[ + fS'(x^{DRG})(C_S + M_S(y^{DRG}) + \beta W(x^{DRG}, y^{DRG})) = 0, \]
\[ (A.7) \]
\[ W'_y(x^{DRG}, y^{DRG})\beta + M'_L(y^{DRG}) = 0. \]  
\[ (A.8) \]

The derivative of \( x^{DRG} \) with respect to \( C_S \) in equation (A.4) is
\[ \frac{dx^{DRG}}{dC_S} \left[ n \theta M_L''(x^{DRG})\right] \]
\[ (1 - \lambda(x^{DRG}) + \lambda(x^{DRG})f) \]
\[ + fS''(x^{DRG})(C_S + M_S(y^{DRG}) + \beta W(x^{DRG}, y^{DRG})) \]
\[ - 2n\theta(1 - f)\lambda'(x^{DRG})M'_L(x^{DRG}, y^{DRG}) \]
\[ + n\theta(1 - f)\lambda\eta(x^{DRG})(B_1 - C_L - M_L(x^{DRG})) \]
\[ + f\beta S'(x^{DRG})W'_y(x^{DRG}, y^{DRG}) \]
\[ = -fS'(x^{DRG}). \]  
\[ (A.9) \]

The derivative of \( x^{DRG} \) with respect to \( \beta \) in equation (A.4) is
\[ \frac{dx^{DRG}}{d\beta} \left[ n \theta M_L''(x^{DRG})\right] \]
\[ (1 - \lambda(x^{DRG}) + \lambda(x^{DRG})f) \]
\[ + fS''(x^{DRG})(C_S + M_S(y^{DRG}) + \beta W(x^{DRG}, y^{DRG})) \]
\[ - 2n\theta(1 - f)\lambda'(x^{DRG})M'_L(x^{DRG}, y^{DRG}) \]
\[ + n\theta(1 - f)\lambda\eta(x^{DRG})(B_1 - C_L - M_L(x^{DRG})) \]
\[ + f\beta S'(x^{DRG})W'_y(x^{DRG}, y^{DRG}) \]
\[ = -fS'(x^{DRG})W(x^{DRG}, y^{DRG}). \]  
\[ (A.10) \]

The derivative of \( y^{DRG} \) with respect to \( f \) in equation (A.4) is
\( \gamma^{DRG} \) is independent of \( C_S \). The derivative of \( y^{DRG} \) with respect to \( \beta \) is
\[ (W''_y(x^{DRG}, y^{DRG})\beta + M_S''(y^{DRG}))dy^{DRG}/d\beta = -W''_y(x^{DRG}, y^{DRG}). \]
From the assumptions, thus, \( dy^{DRG}/d\beta > 0 \).

The Proof of Lemma 5. The derivative of \( x^{DRG} \) with respect to \( f \) in equation (A.4) is
\[
\frac{\mathrm{d}x}{\mathrm{d}f} = n\theta M'_2(x^{\text{DRG}}) + \lambda(x^{\text{DRG}}) f - 2n\theta(1 - f)\lambda(x^{\text{DRG}}) M'_1(x^{\text{DRG}}, y^{\text{DRG}}) + n\theta\lambda(x^{\text{DRG}}) M'_1(x^{\text{DRG}}, y^{\text{DRG}}) + n\theta\lambda M_2(x^{\text{DRG}}) (1 - f)(B_1 - C_L - M_1(x^{\text{DRG}})) + f S''(x^{\text{DRG}})(C_S + M_S(y^{\text{DRG}})) + f\beta S'(x^{\text{DRG}}) W_3'(x^{\text{DRG}}, y^{\text{DRG}}) + \beta W(x^{\text{DRG}}, y^{\text{DRG}})]
\]
\[
= -S'(x^{\text{DRG}})(C_S + M_S(y^{\text{DRG}}) + \beta W(x^{\text{DRG}}, y^{\text{DRG}})).
\] (A.11)

From the assumptions, thus, \(\frac{\mathrm{d}x^{\text{DRG}}}{\mathrm{d}f} > 0\).

The derivative of \(x^{\text{DRG}}\) with respect to \(B_1\) in equation (14) is

\[
\frac{\mathrm{d}x^{\text{DRG}}}{\mathrm{d}B_1} = n\theta M'_2(x^{\text{DRG}}) + \lambda(x^{\text{DRG}}) f + f S''(x^{\text{DRG}})(C_S + M_S(y^{\text{DRG}}) + \beta W(x^{\text{DRG}}, y^{\text{DRG}})) - n\theta(1 - f)\lambda(x^{\text{DRG}}) M'_1(x^{\text{DRG}}, y^{\text{DRG}}) + n\theta(1 - f)\lambda n(x^{\text{DRG}})(B_1 - C_L - M_1(x^{\text{DRG}})) + f\beta S''(x^{\text{DRG}}) W_3'(x^{\text{DRG}}, y^{\text{DRG}}) + \beta W(x^{\text{DRG}}, y^{\text{DRG}})]
\]
\[
= -n\theta\lambda'(x^{\text{DRG}})(1 - f).
\] (A.12)

From the assumptions, thus, \(\frac{\mathrm{d}x^{\text{DRG}}}{\mathrm{d}B_1} > 0\).

**The Proof of Theorem 1.** To make \(x^{\text{DRG}} = x^*\), \(y^{\text{DRG}} = y^*\). It satisfy \(\varphi_3(x^*, y^*) = \varphi_4(x^*, y^*)\). From the Proposition 2, we let

\[
F_1 = S'(x^*)(C_S + M_S(y^*) + \beta W(x^*, y^*)) + \beta S(x^*) W'(x^*, y^*), \quad F_2 = -S'(x^*)(C_S + M_S(y^*) + \beta W(x^*, y^*)) - n\theta l_1(x^*)(C_L + M_L(x^*)). \quad F_3 = S'(x^*)(C_S + M_S(y^*) + \beta W(x^*, y^*)) - \beta S(x^*) W'(x^*, y^*) - n\theta l_1(x^*)(C_L + M_L(x^*)).
\]

Thus, \(B_1 = F_1 = F_3 + \sqrt{(F_1 + F_3)^2 - 2F_1F_3}/2\). \(F_1 = F_3 = \sqrt{(F_1 + F_3)^2 - 2F_1F_3}/2\). \(F_1 = F_3 = \sqrt{(F_1 + F_3)^2 - 2F_1F_3}/2\). \(F_1 = F_3 = \sqrt{(F_1 + F_3)^2 - 2F_1F_3}/2\). When the utility of community hospital and tertiary hospital is nonnegative, we have

\[
\frac{n\theta l_1(x^*)}{B_1} + n(1 - \theta)B_2 \geq S(x^*)(C_S + M_S(y^*) + \beta W(x^*, y^*)) + \beta S(x^*)(C_L + M_L(x^*)).
\]

When the utility of community hospital and tertiary hospital is nonnegative, we have

\[
F_3 \geq \lambda l_1(x^*)/[F_1 + F_3 + \sqrt{(F_1 + F_3)^2 - 2F_1F_3}]/2 - \lambda l(x^*) + S(x^*)(C_S + M_S(y^*) + \beta W(x^*, y^*)) + n\theta l(x^*)(C_L + M_L(x^*)).
\]

**The Proof of Lemma 6.** The proof of Lemma 6 is similar to the proof of Lemma 1, and we omitted.

**Data Availability**

Data are available on request. Request can be sent to Shifu Pan, shifupan1@163.com.

**Conflicts of Interest**

The authors declare that there are no conflicts of interest regarding the publication of this article.

**Acknowledgments**

This study was supported by the National Science Foundation of China (nos. 71531004 and 72071042).
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