System Dynamics Modeling and Simulation on Medical Service Pricing of Government and Hospitals Co-decision

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Abstract: - The methodology of System Dynamics-based modeling is argued to be a powerful and rigorous approach to theory-building. The argument of the paper is underpinned by an application of System Dynamics to the elaboration of a theory in medical service pricing. To improve the current pricing mechanism dominated by the government, the paper sets up the Causal Relationship model of medical service pricing to analyze dynamic equilibrium between various factors. And then this paper breaks the government independent pricing mode and establishes the pricing model based on government and hospitals co-decision that can avoid many existing drawbacks. Furthermore, this paper applies System Dynamics theory to build the simulation model of medical service pricing on Vensim simulation platform. In addition, based on Guangzhou health status, this paper applies this model to simulate the pricing process of Cardiac Output measurement and analyzes simulation results compared with the current price to illustrate the advantages of this model.

Key-Words: - Causal Relationship model, System Dynamics, Delphi method, Pricing model, Cardiac Output Measurement

1 Introduction

The reform of medical service pricing system is priority and difficulty in China's medical system reform[1]. The current medical pricing system in China depends on the medical service items. And this pricing standard is dominated by the government. However, the hospitals, as providers of medical services, play a little role in the pricing process. Thence, the existing pricing mode is an important reason to cause the hospital charge standard to deviate from the actual cost.

First, hospitals are induced to buy large scale equipments for expanding the scale of services and providing inappropriate examination and treatment[2]. In result, hospital costs go up. Secondly, doctors' technical services and knowledge value have not been fully reflected in the process of price formation and adjustment[3]. So doctors will have no enough motivation to deal with the uncertainty and choose different medical technologies and products according to patients' differences. Inevitably, over induced demands are often used to increase revenue, such as more checks, decomposition charges and recurring charges[4]. Thirdly, it is almost unchanged for many years after medical service items and standards are drawn up[5]. In result, hospitals can't get rational compensation. In addition, there is also no pricing foundation for new treatment technologies[6].

To improve the current pricing mechanism, some researchers have proposed the corresponding pricing strategies from different perspectives. The price of medical services should reflect the value of this complex technology, such as service technology, labor intensity and service risk. And Finance and pricing departments should work together to develop plans to guide medical prices[7]. Based on market conditions, the competent authorities of medical and health institutions should allow medical institutions to have certain floating price[8]. According to the principle of combining unified leadership and hierarchical management, management authority is gradually decentralized, so that health authorities and medical institutions may more involve in price research and decision making. Through increasing the service price gap between the medical staffs in various technical positions or different levels of hospitals, it may effectively lead the distribute of patients and improve technology and allocative efficiency of health resources[9].

In addition, numerous articles focused on qualitatively analyzing the competition mechanism and management modes of medical service pricing, little literature applied quantitatively methods such as System Dynamics theory. System dynamics is a methodology and mathematical modeling technique for framing, understanding, and discussing complex issues and problems[10]. It deals with internal feedback loops and time delays that affect the behaviour of the entire system. These elements help describe how even seemingly simple systems display baffling nonlinearity[11]. Originally developed to help corporate managers improve their understanding of industrial processes, system dynamics is currently being used throughout the public and private sector for policy analysis and design[12]. Some experts have applied System Dynamics method in the medical service system, such as the human resource allocation of medical emergency system, game analysis on excessive medical care and compensation for medical manpower mobilization. However, few scholars try to use this method to establish the pricing model of medical services in public hospitals.

Therefore, this study is to devote efforts to establishing the mathematical model and System Dynamics simulation model of medical service pricing according to China's actual conditions.

2 Modeling Process of Medical Services Pricing

This study will improve the current pricing mode of medical services dominated by the government, and set up the pricing method of government and hospitals co-decision. Fig.1 depicts this pricing process and shows the relationships between variables. Character i represents the type of medical service. Character t denotes time.

Step 1.Balancing the cost of medical service i.

The government should build the guidance cost of medical service i in t-1 period (C_{Git-1}) to play the role of limiting and guiding the cost for meeting people's demands for medical services. Therefore, the government always has to depress medical service prices of large hospitals in the current pricing mechanism. However, this is one main reason to cause medical resource shortages of large hospitals. To balance the cost of medical service i, the same grade of public hospitals should calculate the average cost of medical service i in t-1 period (C_{Hit-1}) according to their real expenditure [12]. Because pricing medical services must take both C_{Git-1} and C_{Hit-1} into consideration, the weighted cost of medical service i in t-1 period (C_{it-1}) should be calculated through the average weight coefficient α of C_{Git-1} and the average weight coefficient β of C_{Hit-1}.

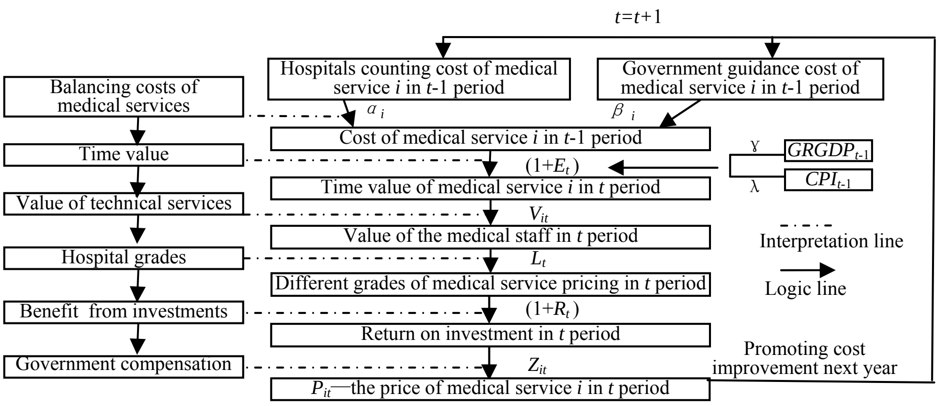

Fig. 1. The modeling process of medical service *i* in *t* period

Step 2. Calculating the time value.

Because medical service costs change with time, the pricing system should be timely adjusted depending on Consumer Price Index (CPI_{t-1}) and the growth rate of local GDP ($GRGDP_{t-1}$) in t-1 period. CPI_{t-1} may represent the price change trend of residents consuming goods or services in t-1 period. In addition, this index change can also reflect the degree of inflation or deflation in a certain extent. And $GRGDP_{t-1}$ may seemly reflect the changes of local economy and human resource costs. In order to balance comprehensive effects of $GRGDP_{t-1}$ and CPI_{t-1}, the comprehensive index of medical resources in t period (E_t) should be calculated by a way of weight coefficient, including the average weight coefficient γ of $GRGDP_{t-1}$ and the average weight coefficient λ of CPI_{t-1}.

Step 3. Considering the technical value coefficient of medical service i in t period (V_{it}).

It is undeniable that the core of medical services is the doctors' diagnosis. However, doctors' technical value, including the consuming time, the technical difficulty and the risk degree, is almost neglected. So under the condition of market economy, the value of medical staff must be reflected in the process of medical service pricing.

Step 4. Considering the hospital grade.

Medical services must be priced in accordance with hospital own grade coefficient in t period (L_t). Because the investments in capital construction, human resources and technical levels are all significant different between different grades of hospitals, treatment costs will be different. That will cause different technical contents and service qualities[13].

Step 5. Calculating the average rate of return on investment in t period (R_t).

Under the market mechanism，as a result of government limited investments, public hospitals should have a certain return on investment to ensure the normal development.

Step 6. Calculating the compensation for medical service i in t period (Z_{it}) .

China's out-of-pocket payments for medical services are higher than other countries with similar or higher GDP. If the government can effectively compensate for the needs of hospital development, public hospitals will not have to impose on patients' unnecessary treatment or examination sheerly for profit. In general, Z_{it} value should be different between different areas or different grades of hospitals.

As a result, the price of medical service i in t period (P_{it}) is established according to above steps. And that cycle repeats next year.

3 Constructing the Causal Relationship model to analyze the dynamic equilibrium of medical service pricing

For studying the system variables of medical service pricing how to accomplish dynamic equilibrium, this paper applies System Dynamics theory to establish its Causal Relationship model based on Vensim simulation platform. The Causal Relationship model is a graphical model with all its constituent components and their interactions, as shown in Fig.2. By capturing interactions and consequently the feedback loops, it reveals the system's structure and ascertains the system's behavior over a certain time period.

The arrow symbol "+" in the model represents a positive correlation relationship between variables, which means that the arrow tail variable can cause the arrow head variable to change in the same direction. And the arrow symbol "-" signifies negative correlation relationship between variables, which means that the arrow tail variable can cause the arrow head variable to change in the opposite direction.

A closed loop along the direction of the arrow is called the feedback loop. Each feedback loop links key variables and surrounding variables. When the number of symbol "-" is even, the feedback loop has a potentiating effect and its attribute is positive. When the number of symbol "-" is odd, the feedback loop has a balancing effect and its attribute is negative. There are two negative feedback loops in the model, as shown in Fig.2 and Fig.3.

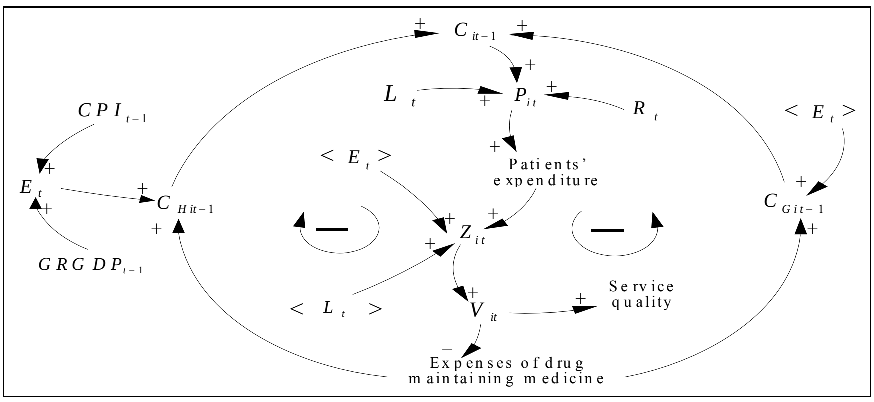

Fig.2. Causal Relationship model of medical service pricing based on System Dynamics theory

In Fig.3, the attribute of this feedback loop is negative.

On one hand, hospitals will increase C_{Hit-1} according to the expense growth of drug-maintaining-medicine. On the other hand, service costs of public hospitals also will change in the same direction along with macroscopic economic environment factors E_t , including CPI_{t-1} and $GRGDP_{t-1}$. Thence, C_{Hit-1} has to rise because of above two aspects. For balancing the difference of hospitals and government on forecasting costs of medical services, C_{it-1} is established. Correspondingly, C_{it-1} will rise with C_{Hit-1} growing. The charge system should be timely adjusted to accurately reflect the costs of health care. As a result, there will be higher medical service price P_{it} to cause the growth of patients' expenditure. But, if government can provide effectively compensate for doctors' diagnosis, public hospitals will not have to rely on higher diagnostic or prescription charges. Therefore, the government will have to enhance Z_{it} in order to prevent the decline of technical value and then limit the expenses of drug-maintaining-medicine. Furthermore, that will be helpful to reduce C_{Hit} . As that cycle repeats, its causal relationship has the balancing effect.

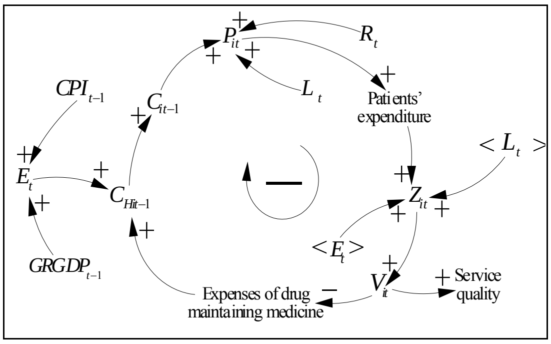

Fig.3. Causal Relationship model base on hospital decision

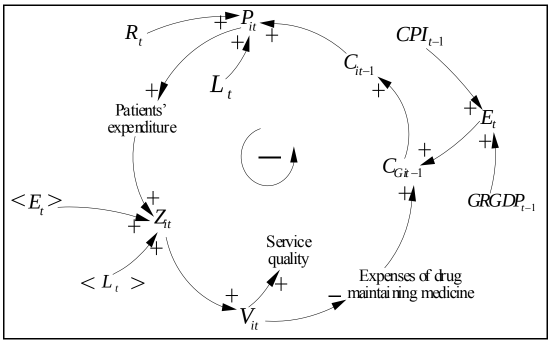

Fig.4. Causal Relationship model base on government decision

In Fig.4, the feedback loop has also the negative attribute and the balancing effect. In this loop, though C_{Git-1} is built to limit and guide medical costs, it will have to change in the same direction with the expenses of drug-maintaining-medicine and the comprehensive index of medical resources. According to C_{Git-1} rising, C_{it-1} has to grow that will form the higher medical price and then cause more patients' expenditure. In order to change this situation, government may decease C_{it-1} through increasing Z_{it} depending on the growth of patients' expenses. As a result, that will guarantee the technical value of the medical staff. Because when doctors' technical value is guaranteed, doctors will improve service quality rather than increase the expenses of drug-maintaining-medicine. In result, C_{it} will fall in next cycle. And that cycle repeats.

Under the joint action of two negative feedback loops, P_{it} will implement dynamic equilibrium.

4 Establishing the System Dynamics Model of Medical Service Pricing

Based on above analysis, the paper applies the System Dynamics method to establish the simulation model of medical service pricing on Vensim simulation platform. As showed in Fig.5, the simulation model includes complex logical relationships and functions.

The simulation functions should comply with the following algorithms.

Definition:

$$Initialtime = 1, Timestep = 1. \tag{1}$$

C_{Hit-1} or C_{Git-1} is mainly composed of labor costs C_{Labor} and other costs C_{Other} . Other costs include material costs, management expense, depreciation expense and so on. In addition, the technical value of medical service i, as one specific cost type, is calculated according to C_{Labor} .

Definition t=1

$$C_{Gi1} = (C_{Labor} + C_{Other})_{Gi1}, C_{Hi1} = (C_{Labor} + C_{Other})_{Hi1}, \quad i = 1 \cdots m \tag{2}$$

$$\alpha_i \cdot C_{Gi1} + \beta_i \cdot C_{Hi1} = (\alpha_i \cdot C_{Gi1} + \beta_i \cdot C_{Hi1})_{Labor} + (\alpha_i \cdot C_{Gi1} + \beta_i \cdot C_{Hi1})_{Other} \tag{3}$$

$$C_{i1} = (\alpha_i \cdot C_{Gi1} + \beta_i \cdot C_{Hi1})_{Labor} \cdot V_{i1} + (\alpha_i \cdot C_{Gi1} + \beta_i \cdot C_{Hi1})_{Other} \tag{4}$$

This paper applies Delphi method to determine the values of α_i and β_i . Delphi method is to ask a group of experienced experts for determining respectively the value of each weight, and then use statistical methods to estimate the average value of each weight.

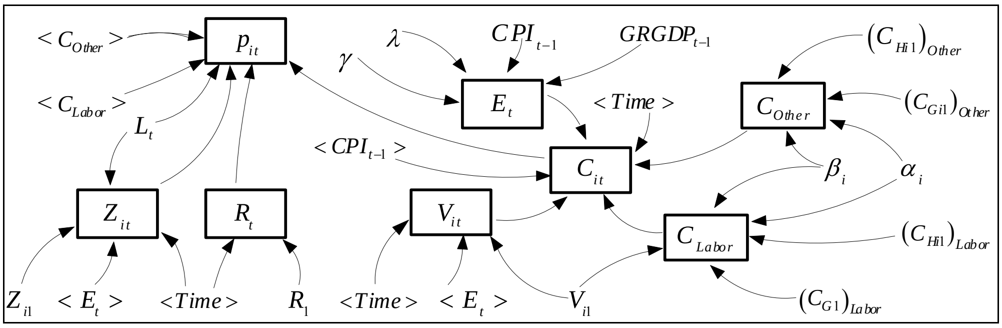

Fig. 5. Simulation model of medical service pricing on Vensim simulation platform

Step1 The detailed background information is sent to Q selected experts. Then each expert j need independently estimate the weight α_{ij} of medical services i, and indicate the confidence level k_{ij} about α_{ij}. k_{ij} denotes the confidence level of expert j estimating weight α_{ij}. k_{ij} value is in [0,1]. When an expert is absolute certainty, $k_{ij}=1$. On the contrary, $k_{ij}=0$.

Step2 Calculating the sample mean $\overline{\alpha_i}$ of weight α_{ij}.

Definition

$$\Omega=\left\{j:k_{ij}\geq S, i=1,2,\cdots,m,\ j=1,2,\cdots,Q\right\}. \quad (5)$$

$$\overline{\alpha}_i=\frac{\sum_{j\in\Omega}\alpha_{ij}}{|\Omega|} \quad (6)$$

Step3 Calculating the variance $D(\alpha_i)$ of weight α_{ij}.

$$D(\alpha_i)=\frac{\sum_{j\in\Omega}[\alpha_{ij}-\overline{\alpha_i}]^2}{|\Omega|-1} \quad (7)$$

Step4 Calculating deviation between the weight α_{ij} and sample mean.

$$\triangle\mu_i=\alpha_{ij}-\overline{\alpha_i} \quad (8)$$

Step5 Based on the results $\triangle\mu_i$, please experts fully express their views for reducing the estimation error in next steps.

Step6 After further supplementary information attached, experts are invited to re-estimate α_{ij}. Repeat the above steps until $D(\alpha_i)$ is no more than a given standard η (η> 1).

$$\alpha_i=\overline{\alpha}_i,\ \beta_i=1-\alpha_i \quad (9)$$

The grade coefficient L_t is used to adjust overall medical costs and government compensation between different grade hospitals. So P_{i1} is defined as follows.

$$P_{i1}=[(\alpha_i\cdot C_{Gi1}+\beta_i\cdot C_{Hi1})_{Labor}\cdot V_{i1}+(\alpha_i\cdot C_{Gi1}+\beta_i\cdot C_{Hi1})_{Other}]\cdot L_1\cdot(1+R_1)-Z_{i1}\cdot L_1 \quad (10)$$

Definition $t=t+1$

E_t is used to balance comprehensive effects of $GRGDP_{t-1}$ and CPI_{t-1} in t-1 period through weight coefficient γ and λ.

$$E_t=\gamma\cdot GRGDP_{t-1}+\lambda\cdot CPI_{t-1} \quad (11)$$

Similarly, γ and λ may be determined by Delphi method. Through analyzing cost constitution, only labor costs C_{Labor} change with E_t. And other costs C_{Other} change only with CPI.

$$C_{it}=(\alpha_i\cdot C_{Gi1}+\beta_i\cdot C_{Hi1})_{Labor}\cdot\prod_{x=2}^{t}(1+E_x)\cdot V_{ix}+(\alpha_i\cdot C_{Gi1}+\beta_i\cdot C_{Hi1})_{Other}\cdot\prod_{y=1}^{t-1}(1+CPI_y) \quad (12)$$

Of course, Z_{it} value should be adjusted with the macro-economic situation.

$$Z_{it}=Z_{i1}\cdot L_t\cdot\prod_{x=2}^{t}\left(1+E_x\right) \quad (13)$$

As a result, the price of medical service i in t period P_{it} is shown below.

$$P_{it}=[(\alpha_i\cdot C_{Gi1}+\beta_i\cdot C_{Hi1})_{Labor}\cdot\prod_{x=2}^{t}(1+E_x)\cdot V_{ix}+(\alpha_i\cdot C_{Gi1}+\beta_i\cdot C_{Hi1})_{Other}\cdot\prod_{y=1}^{t-1}(1+CPI_y)]\cdot L_t\cdot(1+R_t)-Z_{i1}\cdot L_t\cdot\prod_{x=2}^{t}\left(1+E_x\right) \quad (14)$$

$$\alpha_i > 0, \beta_i > 0, \alpha_i + \beta_i = 1, \gamma > 0, \lambda > 0, \\ \gamma + \lambda = 1, V_{it} \geq 1, L_t \geq 1, t = 2 \cdots n \tag{15}$$

5 Simulation and Discussion

Based on Guangzhou health status, this paper studies the pricing process of Cardiac Output Measurement. As shown in Table 1, the initial data of all parameters are determined through the investigation of 20 hospitals. This model assumes that simulation period is ten years and E_t remain unchanged.

In China, public hospitals are divided into three grades. Grade 1 hospitals provide health prevention, medical treatment and rehabilitation services for communities. Grade 2 hospitals mainly undertake common comprehensive health services. Grade 3 hospitals provide a higher level of comprehensive health services and take the missions of higher education and scientific research. Thence, costs of different grade hospitals are certainly different. Correspondingly, L_1 and C_{Hi1} of Grade 3 hospitals are also highest. Based on the technical characteristic and difficulty of Cardiac Output Measurement, V_{i1} value is same and equal to 1.2. Because of hospitals lying in the same region, the effect of $GRGDP_1$ or CPI_1 is no difference. As everyone knows, China's medical services have the characteristic of public welfare. Therefore, R_t value must comply with the premise of no more than the average profit rate of other service industries. In addition, this paper assumes that government will compensate hospitals depending on the specific medical project. Therefore, Z_{i1} is also equal. And average weight coefficients are determined by Delphi method.

Table 1. Simulation parameters of Cardiac Output Measurement

	C_{Gi1} (¥)		C_{Hi1} (¥)		CPI_1	$GRGDP_1$	V_{i1}	L_1	R_1	Z_{i1} (¥)	α	β	γ	λ
	C_{Labor}	C_{Other}	C_{Labor}	C_{Other}										
Grade 1	25	250	26	263	2.2%	7.3%	1.15	1	1.5%	17	0.6	0.4	0.6	0.4
Grade 2	28	278	30	290	2.2%	7.3%	1.15	1.04	1.5%	17	0.5	0.5	0.6	0.4
Grade 3	30	300	32	312	2.2%	7.3%	1.15	1.07	1.5%	17	0.4	0.6	0.6	0.4

Compared with the current price of Cardiac Output Measurement, as shown in Table 2, the simulation results have the following characteristics. Firstly, according to the difference of hospital responsibility and scale, the price gap between different hospitals in this model is larger than in the current pricing system and is still gradually enlarged with time. Of course, the price gap will be conducive to patients' reasonable diversion. While patients suffering from diseases, they commonly select grade 1 hospitals because P_{it} is lowest and even lower than C_{it} that may meet the needs of the patients for basic medical services. If patients suffer from critical illnesses, they will be guided to go to grade 2 or grade 3 hospitals according to the severity and types of diseases. Therefore,the different grades of hospitals may give full play to the respective roles, make full use of limited health resources, and continuously improve core strengths. And facts have proved that current medical prices can not play this role because of the less difference between different grades of hospitals.

Secondly, P_{it} in this model may vary gradually with market factors. But current medical prices are static and do not change with medical costs. If the government doesn't invest more, it will inevitably cause the irrational medical behavior.

Moreover, $P_{it} + Z_{it}$ value must be higher than C_{it} and keep constantly adjustment with C_{it} change. That will stimulate community hospitals to provide better basic medical services and large hospitals to focus in treating incurable diseases and studying high-end medical technologies.

Furthermore, in order to study how to change Z_{it} and P_{it} with E_t revision, this paper assumes that γ is equal to 0.1, 0.3, 0.5, 0.7 and 0.9 in turn. Correspondingly, E_t is equal to 0.0271, 0.0373, 0.0475, 0.0577, and 0.0679 in turn. Judging from the results of the sensitivity test in grade 3 hospitals, as shown in Fig.6 and Fig.7, P_{it} and Z_{it} will gradually rise along with the increase of GDP proportion in local economic structure. Because of economic regionalization and imperfect incentives in the pricing system, the region's fiscal situation will decide to medical service pricing and compensation degree of local public hospitals. If government can effectively compensate for the needs of hospital development, public hospitals will not have to impose on patients' unnecessary treatment or examination sheerly for profit. So the

Table 2. Comparisons of simulation results

	Time(year)	1	2	3	4	5	6	7	8	9	10
Grade 1 (¥)	C_{it}	284.4	291.6	298.9	306.5	314.3	322.3	330.5	339.0	347.7	356.7
	P_{it}	271.7	278.0	284.6	291.3	298.1	305.1	312.4	319.8	327.3	335.1
	$P_{it}+Z_{it}$	288.7	295.9	303.4	311.1	319.0	327.1	335.5	344.1	353.0	362.1
	current price					280					
Grade 2 (¥)	C_{it}	317.4	325.4	333.6	342.1	350.8	359.7	369.0	378.5	388.3	398.3
	P_{it}	317.3	324.8	332.5	340.5	348.6	356.9	365.4	374.2	383.2	392.4
	$P_{it}+Z_{it}$	335.0	343.4	352.1	361.1	370.3	379.7	389.5	399.5	409.9	420.5
	current price					315					
Grade 3 (¥)	C_{it}	343.1	351.7	360.6	369.8	379.2	388.9	398.8	409.1	419.7	430.6
	P_{it}	354.4	362.8	371.5	380.4	389.5	398.8	408.4	418.3	428.4	438.8
	$P_{it}+Z_{it}$	372.6	382.0	391.7	401.6	411.8	422.3	433.2	444.3	455.8	467.6
	current price					350					

government should take into consideration both national and provincial economic levels to set up coordinated medical compensation mechanism. The results are similar in the sensitivity test of grade 1 or grade 2 hospitals.

6 Conclusion

The dynamic pricing model can systematically take into account the logic relationship between pricing factors of medical services, and seemly combine hospital value with the public welfare. Therefore, this pricing model has the following advantages.

First, the weighted cost determined by parameters α , β , C_{Hit-1} and C_{Git-1} can effectively balance the game relationship between public welfare and hospital benefits, and play a restricting and guiding role of medical costs. Secondly, the model may timely track the price changes of medical resources and really reflect the price of medical services by E_t . Thirdly, the value of the medical staff and grades of hospitals are integrated into the model, which can effectively promote hospitals to give full play to the respective roles. Finally, in order to reflect public welfare and local economic conditions, this model defines that Z_{it} value should be determined depending on different diseases and regions.

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