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Knowledge Spillovers of Medical Big Data Under Hierarchical Medical System and Patients' Medical Treatment Decisions

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ABSTRACT In China, there are so many patients go to the highest-level hospitals to get medical treatment directly, it is essential to study how to guide patients to take the initiative to go to the basic medical institutions first in most cases. The information asymmetry theory and the game model are applied for rational analysis in this paper. We construct two models, a doctor-patient signaling game model to study the dynamic process of patients who seek medical treatment to hospitals that are trustworthy, and a two-level treatment game model to study how to achieve a hierarchical diagnosis and reasonable referral in the case of different types of patients (general and serious conditions), considering the knowledge spillover variables supported by big data to analyze the changes in the total utility of the medical market, hospitals, and patients. With the first model analysis, it points out that only when there are three preconditions, namely, high disguising cost, controlling the income of diagnosis and treatment, and reducing the losses caused by untrustworthy behaviors, can trust signals play a real role and achieve the coordination of the optimal market type. In addition to the second model analysis, it is found that the hierarchical medical system with optimizing the allocation of medical resources has a positive effect on the benefit of the medical system and the improvement of the total welfare of patients. It also shows that the full application of big data system can further enhance the total benefit of the medical system under this system. This paper gives management suggestions for strengthening information transmission, rational design of communication system, promotion and application of big data intelligent diagnosis, and treatment for medical management departments and medical institutions at all levels to make decisions.

INDEX TERMS Tiered diagnosis and treatment, big data in medicine, knowledge spillovers, signaling game.

I. INTRODUCTION

In China, the Hierarchical medical system (HMS) is one of the important ways to solve the problem of ''difficult to see a doctor''. However, although it is proposed as ''primary treatment at community level, two-way referral system, different treatments for acute and chronic diseases, and interconnection between different levels'', the HMS has encountered embarrassment in reality. The outpatient rate at community level has not increased in recent years, decreasing from 59.6% in 2013 to 54.2% in 2017.[1] It is worth noting that common diseases and chronic diseases occupy limited resources of top-class hospitals. More than 60% of patients in top-class hospitals can be diverted to low-grade hospitals (Li Yincai, 2015). The mismatch of resources makes the operation of China's medical system deviate from the optimal state. The reasons for mismatch include the income-based benefits of First-class hospitals and doctors, and the patient's blind faith in the quality of First-class hospitals (Wang Wenjuan, Nan Wenzhe, 2016). Constrained by the system, it is difficult to form effective price difference between First-class hospitals and primary hospitals, and the increase in affordability and health utility weakens patients' sensitivity to medical prices (Yao Zelin, 2016).

The application of Internet and big data technology in the medical field is more and more extensive and thoroughly, which has far-reaching influence on both doctors

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[1]Data Source: Statistical Bulletin on the Development of Health Career in China from 2013 to 2017

and patients. Studies have shown that medical information spillovers on the Internet make patients acquire more diversified medical knowledge, improve their self-diagnosis ability, and thus trigger the polarization of treatment options, namely self-diagnosis and get medical treatment at high-level hospitals (Liu Chen, Zhou Xianghong, 2017). The application of medical big data in clinical decision-making and the effectiveness of medical treatment programs has greatly improved the effectiveness in identification and treatment of diseases by doctors and hospitals (Tao C., 2017; Yang CT, 2017; Aphinyanaphongs, 2017); Seward JB, 2017). At the same time, the application of technologies such as smart medical treatment and remote medical diagnosis and treatment can further enhance the service capacity of primary hospitals, and appropriate signal transmission can enhance the trust of ordinary patients for primary medical institutions. Therefore, in addition to internal synergistic factors, the current tiered diagnosis and treatment pays special attention to patients who have improved their learning ability and mastered more medical knowledge, and changes in cognition of hospitals at all levels in the hierarchical medical system and its impact on the entire system.

What kind of medical treatment and admission decision changes will be made by doctors and patients in view of the knowledge spillovers of big data and internet technology based on the hierarchical medical system design? Is it possible to effectively change the current dilemma of low medical treatment at community level by strengthening big data in medical decision-making (for both doctors and patients) and enhancing the signal transmission function of big data? This paper intends to introduce precision medicine and signal enhancement variables provided by big data based on the theory of doctor-patient information asymmetry, and to conduct a game analysis of the relationship between doctors and patients under the hierarchical medical system, trying to solve the problem of ''primary treatment at community level'' of HMS based on the signal mechanism and knowledge governance theory.

II. LITERATURE REVIEW

A. MEDICAL INFORMATION ASYMMETRY AND GAME ANALYSIS

Economist Kenneth J.Arrow pointed out that information asymmetry between doctors and patients will lead to high risks in medical services, and such goods or services are called credence goods (Darby and Karni, 1973). Because the main feature of medical credence goods is the information asymmetry between patients and experts, experts have private information that patients do not have. Therefore, various incomplete information game models are generally established in the literature to analyze problems such as overcharge and over-treatment from different perspectives brought by asymmetric information. For example, search theory conducts a study from the perspective of customers searching for relevant treatment information. The signaling game focuses on the information that customers infer from the expert actions that they do not know, and the proxy model (PA) analyzes customers' (social) incentives for experts (Gong Xianwen, 2004; Zhu Xiaoyong, 2011; Zhang Haochen, 2016; Chen Huifang, 2016, etc.).

Huang Tao and Yan Tao (2009) established a signaling game model from the perspective of trusting commodities, analyzed the phenomenon of over-treatment in medical treatment, pointed out the deceit of excessive medical treatment in the pooling equilibrium, and introduced the consumer knowledge search decision-making and punishment mechanism to investigate its influence on the market equilibrium. Guo Chen et al. (2018) further analyzed the role of the hierarchical medical system in optimizing the allocation of medical resources in the era of big data, pointing out that big data can reduce the cost of disease analysis, promote market efficiency and maximize the utility of both doctors and patients.

B. MEDICAL KNOWLEDGE HETEROGENEITY AND SPILLOVERS

When patients search for medical information through various channels and platforms, the knowledge gained through information exchange becomes medical knowledge spillovers (Caniels, 2000). The essence of knowledge spillovers is that the social rate of return of knowledge is significantly higher than that of private rate of return (Griliches, 1992). Xu wen (2012) refers to the partial or scattered stock of medical diagnosis and treatment that is acquired and received by patients and residents from doctors, or learned and received through the media and knowledge carriers, as a result of medical and prevention practices for diseases as knowledge spillovers. At the same time, the paper studies the relationship between heterogeneous knowledge and knowledge spillovers, and divides medical knowledge into knowledge of common diseases and incurable diseases. It is found that the decision-making induced by different knowledge is different.

The research on Internet medical knowledge spillovers and medical choice not only stimulates the social effect of information technology, but also puts the structural imbalance between supply and demand of medical services from the perspective of technological progress. The level of diagnosis and treatment in primary hospitals is difficult to improve in the short term. In 2014, only 2.3% of community doctors had postgraduate qualifications (National Health and Family Planning Commission, 2015). The administrative resource allocation mode also triggered the Matthew effect of talent flow, and bolster weakness of talent of primary hospitals (Zhu Hengpeng, 2015; Mustata et al. 2017). Internet medical care is an emerging medical model consisting of hospitals, online platforms, and patients. Among them, patients are always the ones with the least information. Information asymmetry in Internet medical treatment will cause adverse selection and moral hazard (Akerlof, 1970). As a channel for patients to obtain information and get to know medical industry, the network platform plays an important role in balancing the relationship between doctors and patients. Once the network platform has inappropriate information dissemination behavior, it will affect the choice of patients' decision-making.

C. THE CHARACTERISTICS OF MEDICAL SERVICES AS CREDENCE GOODS

At present, foreign research on credence goods mainly focuses on medical services and expert consultation. Wolinsky (1993) and Alger and Salanie (2006) argue that under the premise that the market environment is competitive, consumers can search for optimal treatment prices by seeking diagnosis from different experts, and can effectively reduce experts' cheating behavior. Furthermore, as long as the cost of searching for information paid by consumers is not very high, expert's deception can be eliminated in equilibrium. Bonroy et al. (2013) included risk-averse consumers in the standard expert-consultation trust model, and the results showed that the presence of such consumers weakened the enthusiasm of the expert treatment and may lead to inadequate treatment. Bester and Dahm(2014) argue that the best solution to address information asymmetry between patients and experts is to sign contracts for diagnosis and treatment with two different agencies.

The third-party certification mechanism for credence goods has been widely used in countries around the world, especially in developed countries. Third-party certification bodies provide services for all types of credence goods companies to enter the market, effectively disclose effective product information, reduce search costs of consumers, and improve market efficiency (Viscusi, 1978; Lizzeri, 1999). However, many scholars also stressed that although the certification has the theoretical basis for relieving the market failure of credence goods, there will still be insufficient effectiveness in the actual implementation process.

In the medical market, in addition to the role of third-party certification of hospital grades, the hospitals participating in the HMS are actually certified. When patients recognize that primary health care institutions are supported by First-class hospitals in terms of resources and services, and can be directly referred when needed, the degree of trust in primary health care institutions should be moderately improved, which will be conducive to the realization of primary treatment at community level.

III. RESEARCH METHOD

In this section, we will construct two models to show a progressive analysis and discussion, a doctor-patient signaling game model to study the dynamic process of patients who seek medical treatment to hospitals that are trustworthy and a two-level diagnosis and treatment game model to study how to achieve a hierarchical diagnosis and reasonable referral in the case of different types of patients (general and serious conditions), with the considering of knowledge spillover variables supported by big data.

A. SIGNALING GAME MODEL ANALYSIS

The information asymmetry in medical services is mainly manifested as: hospitals acting as an agent have the information superiority of professional medical equipment, medical staff and technology, and accurately understand the quality of its services and medical level; as a client, patients have insufficient capacity and incomplete information to understand the actual capacity and level of a hospital, and can only judge whether the hospital has a true quality of service through open information channels and observations in the process of medical treatment. Based on the rational analysis framework, to increase revenue, hospitals can show their high quality of service and medical ability by sending various credible behavior signals to patients to attract patients to see a doctor; patients can judge the hospital level according to the received signals. It can be regarded that hospitals with high medical level to send credible signals are costless, while hospitals with low medical level need to pay extra camouflage cost for sending credible signals, and pay the cost of broken promises with a certain probability.

1) THE GAME MODEL BETWEEN PATIENTS AND HOSPITALS

The game between patients and hospitals is actually a special dynamic game of incomplete information: signaling game(Wang Wei, Wei Jian, 2012). The hospital is the player with information superiority, and patients are an inferior party of the information asymmetry, and hospitals can only be "judged" according to their performance and 自 the Bayes rule. Assume that there are two types of hospitals: high-level hospitals with strong ability and low-level hospitals with poor ability, which are expressed as h_1 and h_2, respectively. The hospitals know their types, but patients are blind to the type of hospitals, and only know the probability of hospitals with high or low level, that is $p(h_1)$ and $p(h_2)$. Different types of hospitals may deliver credible or incredible signals to patients during the diagnosis process. Obviously, the signals transmitted by the hospital do not necessarily reflect the true type of hospital. Patients will infer the level of the hospitals and adopt different treatment strategies: to see a doctor or not, which is respectively denoted as a_1 and a_2.

Then the game can be expressed as:

① From the type set $H = \{h_1, h_2\}$, the hospital type $h_i (i = 1, 2)$ is randomly selected with the probability $p_1 = p(h_1)$ and $p_2 = p(h_2)$, $p_1 + p_2 = 1$, $p_1 = \alpha$, then $p_2 = 1\alpha$.

② The behavior exhibited by the hospital during the outpatient process can be regarded as a transmission of a credible or untrustworthy signal to the patient, selecting from the signal space $S = \{s_1, s_2, s_3 \ldots, s_j\}$ that it possesses and issuing a signal s_j as the type of signal sent. In this paper, $S = \{s_1 =$ "credible", $s_2 =$ "incredible"$\}$.

③ After observing the signal s_j transmitted by the hospital, the patient uses the Bayes rule to extrapolate (posterior probability) $\tilde{P}_K = p(h_k|s_j)$ through the belief p_k, and chooses an action a_1 from the optional strategy set $A = \{a_1, a_2, \ldots\}$, $a_1 =$ "see a doctor", $a_2 =$ "don't see a doctor".

④ The gains of both doctors and patients depend on the type of sender, the signal sent, and the action of the signal recipient, that is:

Gains of hospitals: $U_H = U_H(h_k, s_j, a_l)$, gains of patients: $U_p = U_p(h_k, s_j, a_l)$.

If a patient chooses a high-level hospital to seek medical treatment, the hospital obtains the gains from the medical treatment, which is expressed as $G_h(> 0)$, and the patient gains from treatment, which is expressed as $G_p(> 0)$; if the patient chooses a low-level hospital (h_2) for medical treatment, hospital gets the same gains, but the gains for the patient is zero because the patient is not appropriately treated causing delays in medical treatment.

Assume that the disguising cost of a "credible" signal from a poorly performing hospital is $C_1(> 0)$, and the opportunity cost of delaying treatment is $C_2(> 0)$. When a hospital sends out an "incredible" signal, failure costs, such as the decrease in number of outpatients and the reputation damage, are expressed as $R_1(> 0)$; for patients, when the hospital sends an "incredible" signal, the psychological damage caused to the patient is $R_2(> 0)$. The signaling game process and gains of both sides are shown in Figure 1. The former value in the benefit set refers to the hospital benefit, and the latter value refers to the patient benefit

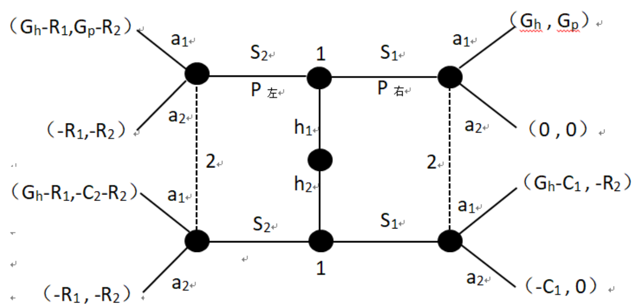

FIGURE 1. **Benefit of doctors and patients in the signaling game.**

2) EQUILIBRIUM ANALYSIS OF DOCTOR-PATIENT GAME

Assume $\tilde{P} = P(h_1|s_2)$, $1-\tilde{P} = P(h_1|s_1)$, that is, the patient's judgment on the type of hospital after receiving the signal from the hospital, making a judgment on the information set on the left side of Fig. 1 $\tilde{P}_{left}(\tilde{P}, 1-\tilde{P})$, assume $\tilde{q} = P(h_1|s_1)$, the patient's judgement on the information set on the right side of Fig. 1 $\tilde{P}_{right}(\tilde{q}, 1-\tilde{q})$.

(1) Partially successful pooling equilibrium in the market

Assume that $R_1 > C_1 - G_h$, When a hospital sends a credible signal, the patient's expected return on medical treatment is E_1.

$$E_1 = P(h_1|s_1) * G_p + P(h_2|s_1)(-C_2) = \tilde{q}G_p + (1-\tilde{q})(-C_2) = \alpha(G_p + C_2) - C_2$$

The expected return of patients not seeking medical care is E_2.

$$E_2 = P(h_1|s_1)(G_p - R_2) + P(h_2|s_1)(-C_2 - R_2) = \mathrm{q} * 0 + (1-q) * 0 = 0$$

Because the patient's posterior probability of a high-level hospital is not less than $C_2/(C_2+G_p)$, namely $\alpha \geq C_2/(C_2+G_p)$, then $E_1 > E_2$, the patient chooses medical treatment strategy.

Therefore, when $R_1 > C_1 - G_h$, the strategy combination and judgement of hospitals and patients are:

$$[(s_1, s_1); (a_1 : a_1); (\tilde{P}_{left}, \tilde{P}_{right})]$$

where in $\tilde{P}_{left} = (\tilde{P}, 1-\tilde{P}), 0 \leq \tilde{P} \leq 1$; $\tilde{P}_{right} = (\tilde{q}, 1-\tilde{q}), C_2/(C_2+G_p) \leq \tilde{q} = \alpha \leq 1$。

Combine a partially successful Perfect Bayesian Equilibrium in the market:

① The hospital sends a credible signal;

② The patient chooses to seek medical treatment;

③ The patient recognizes the credible behavior of the hospital, and the patient's posterior probability of a high-level hospital is not less than $C_2/(C_2 + G_p)$, choosing to go to the hospital.

According to the classification method of market type, this equilibrium belongs to the partially successful equilibrium in the market, that is, the pooling equilibrium (Fu Haimin, Yang Yang, 2015). The high-level and low-level hospitals are all willing to adopt credible behaviors, and patients do not have detection ability and information, but choosing to trust the hospital's medical skills and adopt a medical treatment strategy. When a hospital sends a credible signal that can't transmit the true information of its ability or level, if a patient can't identify the internal quality and capability of the hospital, he can only rely on the limited information obtained from the outside to make random judgments and make medical decisions. In most cases, the hospital's rating information bears the only or major signal function, which makes patients blindly go to higher-level hospitals without distinguishing their pre-conditions such as the type of disease, severity, etc., resulting in more and more difficult and expensive to get medical service.

(2) Completely successful separating equilibrium in the market

When $R_1 > C_1 - G_h > 0$, a hospital sends a credible signal, the patient's expected return on medical treatment is E_1:

$$E_1 = P(h_1|s_1) * G_p + P(h_2|s_1)(-C_2) = \tilde{q}G_p + (1-\tilde{q})(-C_2) = G_p$$

The expected return of patients not seeking medical care is E_2 :

$$E_2 = P(h_l|s_l) * 0 + P(h_2|s_1)^* 0 = 0$$

As$G_p > 0$, then $E_1 > E_2$, the patient chooses to see a doctor.

When a hospital sends an incredible signal, the patient's expected return on medical treatment is E_1':

$$E_1' = P(h_1|s_2)(C_2 - R_2) + P(h_2|s_2)(-C_2 - R_2) = -C_2 - R_2$$

The expected return of patients not seeking medical care is E_2':

$$E_2' = P(h_1|s_2)(-R_2) + P(h_2|s_2)(-R_2) = -R_2$$

As E_1', E_2', the patient does not choose to see a doctor.

Therefore, when $R_1 > C_1 - G_h > 0$, the strategy combination and judgement of hospitals and patients are: $[(s_1, s_2)\ ; (a_1 : a_2)\ ; (\tilde{P}_{左}, \tilde{P}_{右}))]$

Wherein $\tilde{P}_{left} = (\tilde{P}, 1 - \tilde{P}), \tilde{P} = 0$; $\tilde{P}_{right} = (\tilde{q}, 1 - \tilde{q})$, $\tilde{q} = 1$.

Combine a completely successful Perfect Bayesian Equilibrium in the market:

① High-level hospitals send credible signals, and low-level hospitals send incredible signals;

② Patients choose to go to the hospital with credible signal, and refuse to go to the hospital with incredible signals.

③ Patients' judgement is $P(h_1|s_2) = \tilde{P} = 0$; $P(h_1|s_1) = \tilde{q} = 1$; $P(h_2|s_2) = 1 - \tilde{P} = 1$; $P(h_2|s_1) = 1 - \tilde{q} = 0$。

Obviously, when the hospital sends a credible signal, the expected return of patients' healthcare-seeking is greater than the expected return of not seeking medical care. For patients, the medical treatment strategy is absolutely better than not seeking medical treatment. For a hospital, if its ability is strong, it will definitely make credible behavior, the benefit at this time is G_h; if it has poor ability, it must make untrustworthy behavior, then the benefit is -R_1, greater than the benefit of credible behavior G_h-C_1 (because $0 < G_h < C_1$-R_1 at this time), indicating that sending an incredible signal when the level is low is the only strategy for the hospital that conforms to the sequence rationality. At this time, the judgment of the information set of the patient on the equilibrium path conforms to the equilibrium strategy of both parties and the Bayes rule. Under the combination of the equilibrium strategy, there is no information set that needs to be judged on the equilibrium path. Therefore, the above strategy combination and judgment constitute the Perfect Bayesian Equilibrium.

According to the classification of market and equilibrium types, this is a separating equilibrium of a completely successful market, which is the most efficient market equilibrium. In this kind of separating equilibrium, the market is completely successful. At this time, the credible signal plays a role in reflecting the true type of hospital. The patient can rely on the trust behavior of the hospital to judge whether it is a type that can be relied upon. Thereby achieving a virtuous circle and balancing the game.

(3) Completely unsuccessful pooling equilibrium in the market

When $R_1 \geq C_1$, a hospital sends a credible signal, the patient's expected return on medical treatment is E_1.

$$E_1 = P(h_1|s_2) * G_p + P(h_2|s_2)(-C_2)$$
$$= q^{\sim} G_p + (1-q)(-c = \alpha(G_p + C_2) - C_2$$

The expected return of patients not seeking medical care is E_2.

$$E_2 = P\left(h_1|s_2\right)\left(G_p - R_2\right) + P\left(h_2|s_2\right)\left(C_2 - R_2\right)$$
$$= q^{*}0 + (1-q) * 0 = 0$$

Because patient's posterior probability of a high-level hospital is less than $C_2/(C_2 + G_p)$, namely $\alpha < C_2/(C_2 + G_p)$, then $E_1 < E_2$, the patient does not choose medical treatment strategy.

Therefore, when $R_1 \geq C_1$, the strategy combination and judgement of hospitals and patients are:

$$[(s_2, s_2); (a_2 : a_2); (\tilde{P}_{left}, \tilde{P}_{right})]$$

Wherein $\tilde{P}_{left} = (\tilde{P}, 1 - \tilde{P}), 0 \leq \tilde{P} \leq 1$; $\tilde{P}_{right} = (\tilde{q}, 1 - \tilde{q}), 0 \leq \tilde{q} = \alpha < C_2/(C_2 + G_p)$。

Combine a completely unsuccessful Perfect Bayesian Equilibrium in the market:

① Both high- or low-level hospitals send a credible signal;

② The patients refuse to seek medical treatment;

③ The patients' judgment is that they do not recognize the trusted behavior of the hospital, the posterior probability of the high-level hospital is less than $C_2/(C_2 + G_p)$, so they choose not to seek medical treatment.

At this time, the credible signal completely loses its function of reflecting the true type of a hospital, and patients cannot judge whether it is a reliable type based on the trust behavior of the hospital, and generally doubt the ability of the hospital, so it is difficult to achieve doctor-patient cooperation. The hospital credible behavior mechanism will be completely unable to work, and the market is failure completely.

3) DISCUSSION OF THE MODEL ANALYSIS

From the analysis of the signaling game of hospitals and patients, it can be seen that the Perfect Bayesian equilibrium of hospital's credible behavior successfully reflects the true type of the hospital lies in the relationship between the parameters G_h, R_1 andC_1, and the patient's belief α in the hospital type in the pooling equilibrium also lies on the parameters C_2 and G_p. The efficiency of the medical service market decreases as the disguising cost decreases, the income of medical treatment increases, and the losses caused by untrustworthy behavior increases. Conversely, it demonstrates that only when there are three preconditions, namely, high enough disguising cost, control of medical income and reduction of losses caused by untrustworthy behavior, can credible signals play a real role and achieve the coordination of the optimal market type (see Figure 2)

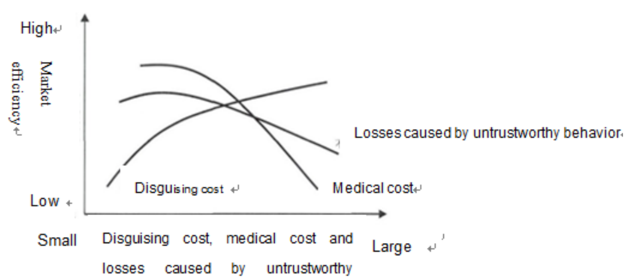

FIGURE 2. Disguising cost, medical income and losses caused by untrustworthy behavior.

How to raise disguising cost, control the income of medical treatment, and reduce the losses caused by untrustworthy behavior? From the perspective of China's practice, on the one hand, the implementation of ''national health insurance, medical insurance payment, and separation of medical treatment and drug sales'' reduce the income of medical treatment in general, and improve the medical service fee to ensure the reasonable income of hospitals and doctors, which basically is a collection of measures to control the income of medical treatment. On the other hand, the channels and modes for patients to obtain medical information are increasingly rich and diversified. As the learning ability of patient increases, the level of judgment on the quality of medical services continues to increase, indirectly promoting the disguising cost of weak hospitals. As information becomes more and more abundant, the losses caused by incredible behavior of hospitals are also decreasing.

Then, after the patients have acquired certain information identification ability and self-diagnosis skills, can the HMS based on big data support run smoothly? In this paper, we further build a game model that considers the impact of big data and Internet-supported medical knowledge spillovers on the HMS, and conducts corresponding game analysis.

B. TWO-LEVEL DIAGNOSIS AND TREATMENT GAME MODEL

There are two players in the game of the model, namely patients and hospitals. Based on the rational analysis framework, patients have certain medical knowledge and self-diagnosis ability, can distinguish the severity of the disease, and also search public information to help them make decisions for diagnosis and treatment decisions. Without loss of generality, the patients are divided into ordinary patients (OP, general diseases) and critically ill patients (CP, serious diseases). Both hospitals and patients are pursuing the goal of maximizing profits (the patients pursue the cure of the disease with the lowest cost, and the hospitals pursue the maximum benefit or minimum medical costs).

This study discusses two-level diagnosis and treatment model (first-class hospitals and second-class hospitals). In an ideal HMS mode, ideal, first-class hospitals treat ordinary patients, and second-class hospitals treat critically ill patients. The patient's strategy space is: $S_1, S_2 = \{$first-class hospitals' treatment, second-class hospitals' treatment$\}$ (S_1 and S_2 represent the strategy space of ordinary and critically ill patients respectively), while the hospital's strategy space is $S_3, S_4 = \{$clinical reception, referral$\}$ (the strategy space of first-class hospitals and second-class hospitals respectively).The payment is as follows:

(1) The gains from treatment of OPs in first-class hospitals is m_1, and gains from treatment of patients in second-class hospitals is m_2, and $m_2 > m_1$;

(2) The medical treatment cost of patients is c_1 in first-class hospitals, c_2 in second-class hospitals, and$c_2 > c_1$;

(3) If CPs choose to get medical treatment in first-class hospitals, it may delay treatment and pay additional costc_d(human cost), hospital loss m_d;

(4) To improve medical accuracy by introducing big data and intelligent diagnosis and treatment system, the patient's identifying cost is represented as c_z, $c_z \leq m_1 < m_2$(Table 1). (the cost of adoption big data and intelligent diagnosis and treatment system is not considered at this moment.)

TABLE 1. Representations of variables.

Variables	Type of expense	Meaning
m_1	Income from treatment of OPs	Income from treatment of ordinary patients in first-class hospitals
m_2	Income from treatment of CPs	Income from treatment of critically ill patients in second-class hospitals
c_1	Medical costs of first-class hospitals	Medical treatment cost of patients in first-class hospitals
c_2	Medical costs of second-class hospitals	Medical treatment cost of patients in second-class hospitals
c_d	Loss cost of patients for delayed diagnosis and treatment	Loss cost caused by the patients' delayed diagnosis and treatment
m_d	Hospital loss for delayed diagnosis and treatment	Cost paid by hospitals for delayed diagnosis and treatment
c_z	Patient analysis cost of precision medicine	Identify patients' diseases relying on big data and intelligent diagnosis and treatment system

1) COMPARISONS OF TWO MEDICAL SYSTEMS

1. In Case of the traditional medical system

In the traditional medical system, medical resources are highly concentrated in high-level hospitals, and patients tend to go directly to there to improve the accuracy of diagnosis and enjoy high-level treatment techniques. According to the hypothesis of this paper, such situation is equivalent to the existence of only second-class hospitals, assuming that the total number of patients is N, the number of OPs is qN, and the CPs is $(1-q)N$, $q \geq (1-q)$.

The hospitals' total utility is:

$$U_h = \bar{M} - qNm_2 + (1-q)Nm_2 = -Nm_2 \tag{3-1}$$

where $\bar{M}$ refers to total utility of the medical service market in the region, the total utility of the hospital is the total market income minus the total patient income.

OPs and CPs both accept treatment in second-class hospitals, and the total patient utility is:

$$U_b = \bar{M} - qNc_2 + (1-q)Nc_2 == \bar{M} - Nc_2 \tag{3-2}$$

Therefore, there is no difference in the medical resources between Ops and CPs, which inevitably leads to double loss of medical and patient utilities.

The patient identifying mechanism fails under the traditional medical mode, and the payoff matrix of patients and medical institutions is shown in Table 2.

TABLE 2. Payoff matrix of patients and hospitals in traditional mode.

Type of patients	First-class hospitals		Second-class hospitals	
	Clinical reception	Referral	Clinical reception	Referral
Ordinary patients	c_1,m_1	c_2,m_2	c_2,m_2	c_1,m_1
Critically ill patients	c_1,m_1 or c_1+c_d,m_1+m_d	c_2,m_2	c_2,m_2	c_1,m_1 or c_1+c_d,m_1+m_d

2. In Case of the hierarchical medical system(HMS)

The HMS advocates "primary treatment at community level, two-way referral system", and guides most OPs to the primary hospitals (first-class hospitals in our model) for medical treatment. Suppose that the patients can choose medical institution by themselves, the probability that the average patients go to first-class hospitals is p_1, the probability of going to the second-class hospitals is $(1\text{-}p_1)$; the probability that the CPs go to the first-class hospitals is p_2, and the probability of going to the second-class hospitals is $(1\text{-}p_2)$, and $1\text{-}p_2 \geq p_2$. When a CP goes to a first-class hospital, there may be a delay in treatment, suppose the probability of causing serious consequence isP_d, then $(1\text{-}p_d)c_1 + p_d(c_1 + c_d) > c_2$. While the HMS without big data information identifying mechanism, when the hospital choice is clinical reception, the total utilities of the medical system is:

$$\begin{aligned} U_{fh} &= \bar{M} - p_1qNm_1 - (1-p_1)qNm_2 - p_2(1-q)N((1-p_d) \\ &\quad m_1 + p_d(m_1+m_d)) - (1-p_2)(1-q)Nm_2 \\ &= \bar{M} - Nm_2 + (p_1-p_2)qN(m_2-m_1) - p_2p_d(1-q)Np_dm_d \end{aligned} \quad (3\text{-}3)$$

As $q \geq (1-q)$ and $1-p_2 \geq p_2$, thus:

$$m_2(p_1-p_2)qN(m_2-m_1) - p_2p_d(1-q)Np_dm_d > 0 \quad (3\text{-}4)$$

Namely, the total hospital utility under the HMS is greater than the total hospital utilities ($U_{\mathrm{fh}} > U_{\mathrm{h}}$) under the traditional mode, indicating that the HMS can improve the efficiency of the medical system.

For patients, the total utilities is:

$$\begin{aligned} U_{fd} &= \bar{M} - p_1qNc_1 - (1-p_1)qNc_2 - p_2(1-q) \\ &\quad \times N((1-p_d)c_1 + p_d(c_1+c_d)) - (1-p_2)(1-q)Nc_2 \\ &= \bar{M} - Nc_2 + (p_1-p_2)qN(c_2-c_1) - p_2p_d(1-q)Nc_d \end{aligned} \quad (3\text{-}5)$$

Previously $q \geq (1\text{-}q)$and $1\text{-}p_2 \geq p_2$, thus:

$$(p_1-p_2)\,qN\,(c_2-c_1) - p_2p_d(1-q)Nc_d > 0 \quad (3\text{-}6)$$

Therefore, the HMS can also improve the total utility of patients, indicating that the HMS can optimize the allocation of medical resources to the corresponding patients to improve the overall utility of patients.

When there are referrals, it is divided into three cases, namely, only referral of first-class hospitals(U_{fh1}), only referral of second-class hospitals(U_{fh2}), and referral of both(U_{fh3}), the total hospital utilities are:

$$\begin{aligned} &U_{fh1} \\ &= \overline{M}_{-p_1}qNm_{2-}\,(1-p_1)\,qNm_{2-}(1-q)Nm_2 = \overline{M} - Nm_2 \end{aligned} \quad (3\text{-}7)$$

$$\begin{aligned} &U_{fh2} \\ &= \overline{M} - p_1qNm_1 - (1-p_1)\,qNm_1 - (1-q) \\ &\quad \times N\,((1-p_d)\,m_1 + p_d\,(m_1+m_d)) \end{aligned} \quad (3\text{-}8)$$

$$\begin{aligned} &U_{fh3} \\ &= \overline{M} - (1-p_1)\,qNm_1 - p1qNm_2 - (1-p_2)\,(1-q) \\ &\quad \times N((1-p_d)m_1 + p_d\,(m_1+m_d)) - p_2(1-q)Nm_2 \\ &= \overline{M} - Nm_2 - (p_1-p_2)\,qN\,(m_2-m_1) - p_2p_d(1-q)Np_dm_d \end{aligned} \quad (3\text{-}9)$$

According to formula (3-7) to (3-9), the total hospital utilities is equal to that under the traditional mode only when referral of first-class hospitals, and the total hospital utilities is based on $q \geq (1\text{-}q)$ and $1\text{-}p_2 \geq p_2$ only when referral of second-class hospitals, which is lower than the total hospital utilities under the strategy of clinical reception. The total utility under the condition of referral is lower than the total utility under the traditional mode.

$$\mathrm{U_{fb}} > \mathrm{Uf_{h2}} > \mathrm{Uf_{h1}} > \mathrm{U_h} > \mathrm{U_{fh3}} \quad (3\text{-}10)$$

Therefore, the HMS of first-class hospitals and second-class hospitals both choose the clinical reception strategy.

In summary, it has been found that the HMS oriented by the optimal allocation of medical resources has a positive effect on the benefits of the medical system and the improvement of the total welfare of patients.

2) THE INFLUENCE OF MEDICAL KNOWLEDGE SPILLOVERS

Medical knowledge spillovers and medical big data should be adopted in the medical system to provide more technical support, improve the hospitals' disease screening ability, and improve the accuracy of clinical reception or referral. At this point, the hospitals can identify patients and their diseases at a lower cost (Table 3).

Under normal circumstances, the first-class hospitals do not need to transfer the OPs to the second-class hospitals, nor to receive the CPs; the second-class hospitals do not receive the OPs, and do not need to transfer the CPs to the first-class hospitals. The first-class and second-class hospitals rely on the medical big data system to analyze the patients' conditions and select the clinical reception or referral strategy. At this time, the total utility of the medical system is:

$$\begin{aligned} U_{dfh} &= \overline{M} - p_1qN\,(m_1+c_Z) - p\,(c_Z)\,(1-p_1)\,q \\ &\quad \times N\,(m_l+c_Z) - (1-p\,(c_Z))\,(1-p_D)qNm_2 - p_2(1-q) \end{aligned}$$

TABLE 3. Payoff matrix of patients and hospitals in big data mode.

Type of patients	First-class hospitals		Second-class hospitals	
	Clinical reception	Referral	Clinical reception	Referral
OP(ordinary patients)	c_1,m_1+c_Z	c_2,m_2	c_2,m_2	c_1,m_1+c_Z
CP(critically ill patients)	c_1, m_1+c_Z or c_1+c_d,m_1+m_d	c_2,m_2+c_Z	c_2,m_2+c_Z	c_1,m_1+c_Z or c_1+c_d,m_1+m_d

$$\times N\left((1-p_d)\, m_1+p_d\,(m_1+m_d)\right) - (1-p\,(c_Z))\,(1-p_2)(1-q)\,((1-p_d)\,m_1+p_d\,(m_1+m_d)) - p\,(c_Z)\,(1-p_2)\,(1-q)Nm_2 \quad (3\text{-}11)$$

When the accuracy of disease analysis is improved under the support of big data,$p\,(c_z)$will be infinitely close to 1, and formula (3-11) can be reduced to:

$$U_{dfh} = \overline{M} - qN(m_1 + c_Z) - (1 - q)N(m_2 + c_Z) \quad (3\text{-}12)$$

and $c_Z \leqslant m_1 < m_2$, thus:

$$qN(m_2-m_1)-Nc_Z > (p_1-p_2)qN(c_2-c_1)-p_2p_d(1-q)Nc_d \quad (3\text{-}13)$$

$U_{dfh} > U_{fh}$ can be obtained from formula (3-13), indicating that the full application of medical big data system for intelligent medical treatment and accurate analysis can further improve the total utility of the medical system under the HMS, and the total patient utility is also $U_{dfp} > U_{fb}$, indicating that the HMS supported by big data can further increase the total utility of patients.

IV. CONCLUSIONS

This paper mainly explores the problem of decision-making for medical treatment based on information asymmetry between patients and hospitals, and analyzes whether the guiding effect on patients' medical treatment decision can be realized after improving the level of diagnosis and treatment of hospitals and enhancing the hospitals' signal transmission function based on the application of medical big data, to solve the dilemma of low-level primary treatment at community level under the HMS.

First of all, it can be seen from the doctor-patient signaling game model that only when there are three preconditions, namely, high disguising cost, controlling the income of diagnosis and treatment and reducing the losses caused by untrustworthy behaviors, can credible signals sent by hospitals play a real role and achieve the coordination of the optimal market type. This provides a theoretical basis for implementation of the "separation of medical treatment and drug sales, medical insurance payment" in the HMS, and the promotion of medical big data integration and application. Secondly, from the two-level diagnosis and treatment game analysis, it can be seen that only when patients have certain medical knowledge and a preliminary judgment on their own condition, can better and reasonable medical decisions be made; and the adoption of big data system can greatly reduce the difference between the condition and the cost of screening, thus significantly improving the total utility of the medical system (win-win of hospital revenue and patient), which demonstrates that the application of the Internet and big data technology can significantly improve the efficiency of the medical service market and protect the rights and interests of majority of practitioners and consumers.

According to the above analysis, the following strategies can be proposed for reference by management departments and medical institutions:

(1) Pay full attention to signal transmission in medical services. If patients can acquire more internal information of medical institutions at all levels, especially the positive information of medical equipment, technical level and service level of primary medical institutions, they can greatly enhance their trust and choose to get medical service in a targeted manner, which can greatly alleviate the problem of "difficult to see a doctor" in high-grade hospitals. The basic strategy is to collect, collate and publish information such as resources or technical support obtained by the primary medical institutions under the HMS, the implementation of clinical pathways, the application of big data telemedicine technology, the improvement of medical service, and typical medical treatment cases, which are transmitted to patients through effective information channels to achieve the transmission of trusted signals.

(2) Design a doctor-patient communication system for patient information needs. With the development of social economy and the wide application of IT(information technology), the basic quality of the people has been continuously improved, the awareness and ability of information search have been continuously improved, and there have been more and more self-diagnosis behaviors. The demand for information in medical treatment has also been continuously enhanced. Therefore, for critically ill patients, primary treatment rate at community level is not necessarily a necessary procedure. A low-level primary treatment at community does not necessarily mean a problem with the implementation of HMS; in addition to the accuracy in the diagnosis and treatment process, we must pay attention to doctor-patient information communication and knowledge popularization. To win more patients' trust and cooperation, improve patients' cognitive level through knowledge spillovers.

(3) The application of big data and artificial intelligence technology improves the efficiency of the medical service market. While big data and artificial intelligence technology improve the level of diagnosis and treatment and the quality of medical care, the released macroscopic effects enhance the total utility of the medical service market. Both the technological revolution and the institutional revolution

should be promoted. The intensity and progress of technology adoption should be strengthened and the technology dividend should be utilized to guarantee the implementation of medical reform.

As we have seen that, medical information and knowledge can not only improve the efficiency of diagnosis and treatment, but also have complex spillover effects on patients. However, due to the limitations of research methods and models, this paper only focuses on the choice of consultation and the application of big data caused by the change of cost and utility based on rational hypothesis, and the management suggestions are not operable enough. The decision-making is a process of the comprehensive measure of subjective and objective utility. In the future, it is needed to make detailed research and analysis of the decision-making psychology of patients and doctors based on the theory of organizational behavior, the management suggestions based on these researches can be more operational to direct medical practices.

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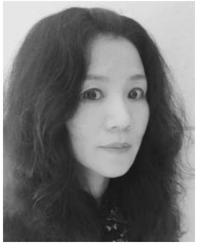

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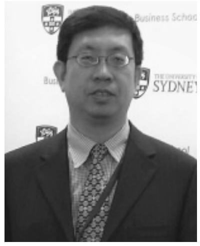

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