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ABSTRACT

Family physicians play a prominent role in the primary health care system of several countries and regions. This study examined family doctors, community residents, and general hospitals, and found that their behaviour and decisions were inevitably affected by multiple economic concerns. To explore the influence of these economic factors, we established a tripartite evolutionary game model. Based on this dynamic game model, we examined the equilibrium of their interactions, effects of relevant parameters, and evolution trends of different scenarios. The main result shows that the participation of general hospitals is crucial to the construction of the family doctor service; that is, to develop the family doctor service, the government should focus on financial compensation for general hospitals rather than for family doctors. We further concluded that the compensation mechanism of contracted services plays a vital role in attracting physicians' participation; thus, policymakers should consider these in different stages of the promotion of the family doctor service.

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Introduction

In coping with the COVID-19 pandemic, the National Health Commission of the People's Republic of China highlighted the fundamental role of primary health care services in the medical and health service system (Li et al., 2020). In fact, all major national healthcare service systems worldwide are paying great attention to their role, along with the integration of the government and the market, and the flexible and effective referral channel. Unlike the national healthcare systems in several countries, such as the USA, Japan, and Germany, the prominent role of primary healthcare service in China has not been well explored because of multiple reasons and the development of hierarchical diagnosis varies greatly in different regions. In 2015, the Chinese government proposed establishing a hierarchical diagnosis system as an important reform measure to ensure the availability of medical services. Since then, some typical models have emerged in China, including the Shenzhen Luohu Hospital

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Group model and Shanghai Changning '1 + 1 + 1' model. These models proved that the implementation of hierarchical diagnosis is inseparable from the deployment of the family doctor service (FDS). FDS has been recognised as an efficient approach for first diagnosis in many other countries and its implementation is of great significance (Wang et al., 2017).

As gatekeepers of primary medical services, family doctors (also known as general practitioners) can provide residents with health management, basic public health services, disease diagnosis and treatment, and two-way referral services (Moore et al., 1983). The FDS was introduced in China in the 1980s; however, it is still in its infancy after approximately 30 years of development. There are many differences between the FDS in China and other countries. First, most family doctors in China are employed by public community health service institutions and are paid monthly by the government. Second, the salary composition of family doctors in China is similar to that of most specialist doctors in the public system, consisting of a basic salary, merit pay, and bonus. Third, the service contents of Chinese family doctors are limited to public services, covering some key populations, such as chronic disease patients, the elderly, the disabled, and pregnant women.

To provide all citizens with comprehensive, coordinated, and preventive public health services, the Chinese government proposed the establishment of the FDS in 2016. According to this plan, family doctors will establish stable, long-term relationships with contracted residents. Additionally, with the help of online platforms, general hospitals can assist family doctors and stimulate their enthusiasm through expert video presentations, classic medical case studies, and clinical reviews of imaging diagnoses. Family doctors supported by general hospitals can strengthen the continuity of medical services, thereby promoting the participation of potential community residents and providing better medical care to the contracted residents.

However, there are still some issues that prevent further development of FDS in China, resulting in poor performance and unexpected problems. For example, residents cannot enjoy medical insurance reimbursement for medical treatment of family doctors, economic incentives are unclear, and the overall supply of family doctors is insufficient. *Healthy China 2030* proposes building an innovative medical and health service system and calls for a new FDS system. Therefore, in this study, we explore the key factors that influence the development of FDS.

Most research on FDS in China are policy-based and empirical, focusing on the demand side. There is inadequate scientific evidence of the behaviour of FDS stakeholders (Jing & Fang, 2020). Existing research are mostly in the medical and behavioural sciences, with few macro theoretical explorations; systematic discussions are even rarer. Therefore, it is of great significance to systematically study the relevant measures for the development of family doctor contract services in China. As independent participants of FDS, family doctors, community residents, and general hospitals have their own interests in providing the service, and their interactions determine the direction of FDS development. Various factors may influence the behaviour of all participants, such as contracting costs, subsidies from the government, and insurance reimbursement ratio. In this study, we build an evolutionary game to theoretically examine the interactions of FDS participants and explore the effects of some economic policies on FDS development. Compared to many other countries or regions with a well-developed FDS, China has a large population who mainly rely on a public healthcare system that has many unsuitable policies and mechanisms. Therefore, this study can further provide a new theoretical perspective for improving the development of family doctor contracting services in China. Additionally, the results can provide a new theoretical basis for the effect of financial incentives on improving the quality of medical and health services. Specifically, our research aims to address this research gap by answering the following questions:

1. How do some factors (the expected signing benefits, cooperation method, economic incentive, etc.) affect the behaviour of FDS participants in China?
2. What factors are critical to FDS development and how do they influence its development?
3. How can we promote FDS in China and other similar countries?

Compared to existing studies, our work enriches this research field in two ways. First, we could fill the research gap that there is a lack of theoretical analysis on FDS participants in China and other similar countries and regions. Additionally, we examined the interaction mechanisms between participants in FDS and explored the effects of different economic policies on those interactions.

The rest of the paper is organised as follows. We conduct a literature review in Section 2 and identify the research gap. The problem setting and some assumptions are presented in Section 3, while the analysis of the model is presented in Section 4. A simulation of the problem is conducted in Section 5, and we conclude with managerial insights in Section 6.

Literature review

Three streams of literature are highly related to our work: the development of FDS in China; the interaction between general hospitals, family doctors, and community residents; and the application of evolutionary game theory in health care.

Regarding the development of FDS in China, Lai et al. (2021) found that FDS could improve the health quality of residents. Family doctor policy has played a positive role in narrowing the medical and health gap among regions (Huang et al., 2020) and can help improve the quality of primary care (Feng et al., 2020). Shang et al. (2019) investigated the demand for FDS projects of residents in Zhejiang Province. They found that–health consultation, regular physical examination, medical insurance reimbursement, continuous nursing of chronic patients, rehabilitation guidance, and appointment referral– had the highest overall demand. Through exploratory factor analysis, Huang et al. (2018) found that non-communicable diseases, FDS awareness, satisfaction, visit compliance, and sociodemographic variables are significant predictors that affect family doctors' signing behaviour. Robert et al. (2015) compared the roles and training of primary care doctors in China, India, Brazil, and South Africa. Through a questionnaire survey, Xu et al. (2020) examined family doctors in Shanghai, Nanjing, and Beijing and found that mental health and work investment significantly affected the performance of FDS in China. Li et al. (2017) pointed out the insufficient training of family doctors in China and the high job burnout rate. Additionally, the payment scheme does not reward doctors who provide high-quality medical services; consequently, many young doctors consider quitting. Through a panel data analysis, Zhou et al. (2020) proved that relevant policies should be adopted to increase the supply of family doctors, such as providing financial incentives and more attractive payment rules. Our research aims and methods differ from existing literature, as they either qualitatively analysed the construction of FDSs in China or used an empirical method to explore factors that have an impact on the promotion of this service. In this study, we investigate the interactions among general hospitals, doctors, and residents and examine the effects of different economic policies using a dynamic game model.

There is abundant literature on the interactions between general hospitals, family doctors, and community residents. Huang et al. (2020) conducted a population-based retrospective cohort study and found that although the implementation of FDS does not reduce the medical utilization rate, it may reduce the hospital admission rate in the long run. Fung et al. (2015) assessed the utilization rate of hospital emergency and special services by different types of primary care doctors in Hong Kong and demonstrated the superiority of the family doctor-led primary care services adopted in Hong Kong and other Asian countries. Yuan et al. (2019) showed that multi-sectoral cooperation is key to implementing FDS in China through the comprehensive framework for implementation research (CFIR). Millares Martin (2021) found that standardised information sharing can promote continuity of care among family doctors and general hospitals through non-systematic evaluation methods. Joubert and Lasagna (1975) suggested that the service package is critical to patients' choice to sign a family physician. Karlsson (2007) showed that social welfare is higher when family physicians provide a menu contract rather than a simple capitation regime. Zhang et al. (2019) empirically explored the factors that influence residents' decisions to sign up with family physicians and found that some factors, including educational level and medical insurance, are critical. In comparison, our study focuses on predicting the development of FDS in China, exploring ways to promote cooperation among family doctors, general hospitals, and residents, and providing practical suggestions for better development of FDS in China and other similar countries/regions.

The last stream of literature relates to the application of evolutionary game theory in economics, especially in healthcare. With the increasing awareness of the irrationality of decision-makers, evolutionary game theory has been widely applied to many academic fields, such as international trade analysis (Taşbaşı, 2017), mobility of workers (Sun et al., 2018), quality control problems (Yang et al., 2019), and policy impacts (Luqman et al., 2021). In healthcare, Chen et al. (2020) explored the investment behaviour of institutions and medical institutions in the integration of health and care services for older people. Kabir (2021) investigated the effectiveness of several vaccines and their risk perception in the human vaccine dilemma using an evolutionary game model. Liu et al. (2020) investigated collaborative innovation among biomedical engineering enterprises, universities, research institutes, public hospitals, and private hospitals in the biomedical engineering industry. In preventing the spread of

COVID-19, Amaral et al. (2021) adopted an evolutionary game to build an epidemiological SIR (susceptible, infectious, and/or recovered) model and analysed the strategy adoption of individuals during the pandemic. They found that risk perception played a fundamental role in the evolution of infection. Fan et al. (2021) also explored the interactions among the government, community, and residents during a public health emergency and proposed a dynamic reward and punishment mechanism to control the epidemic. Kabir and Tanimoto (2020) and Kabir et al. (2021) combined compartmental epidemiological and evolutionary game models to evaluate the options for responding to the COVID-19 pandemic. They revealed the impact of prevention policies, including economic shutdowns and shield immunity, on pandemic control. Yong and Choy (2021) focused on the free-riding phenomenon and highlighted the utility and limits of evolutionary game theory approaches for COVID-19 management. As indicated in previous literature, an evolutionary game model can effectively analyse the interaction between participants in healthcare activities. Thus, this study adopts it to explore the interactions among hospitals, doctors, and residents in the FDS.

Problem setting and assumptions

Conceptual model

Three key groups are involved in FDS: family doctors, community residents, and general hospitals. Family doctors are service providers, whereas residents are receivers of the FDS. Meanwhile, general hospitals provide family doctors with better medical instruments, tests, and other resources, which increases the quality of service of family doctors and enhances its attractiveness to residents (Xu et al., 2020). The behaviour of these three groups is critical to the development of FDS. Similar to most decision-makers, these participants have bounded rationality in decision-making; that is, to maximise their own interests, they will adjust their actions by continuously observing their own environment and other players' reactions. The interaction among these groups is complicated; there is both cooperation and competition among them, with many factors affecting their response. Although most hospitals in China are public-operated and doctors are paid by the government, hospitals and doctors are encouraged to make profits or at least break-even. Therefore, factors such as contracting costs, subsidies, and other economic factors will affect the behaviour of doctors and hospitals in FDS.

To explore the development of FDS in China, we must consider their interactions. Specifically, we built a game model consisting of family doctors, community residents, and hospitals to shed light on this research problem. All participants involved have bounded rationality and focus on the long-run equilibrium of their behaviours.

Based on the current situation of FDS in China, we assume that family doctors can provide two service packages, the basic and personalised packages (Huang et al., 2020). The basic service package provides contracted residents with basic medical services, including first diagnosis, while the personalised service package further includes designed services such as chronic disease management. A family doctor may either provide high- or low-quality service to the contracted residents. The two work

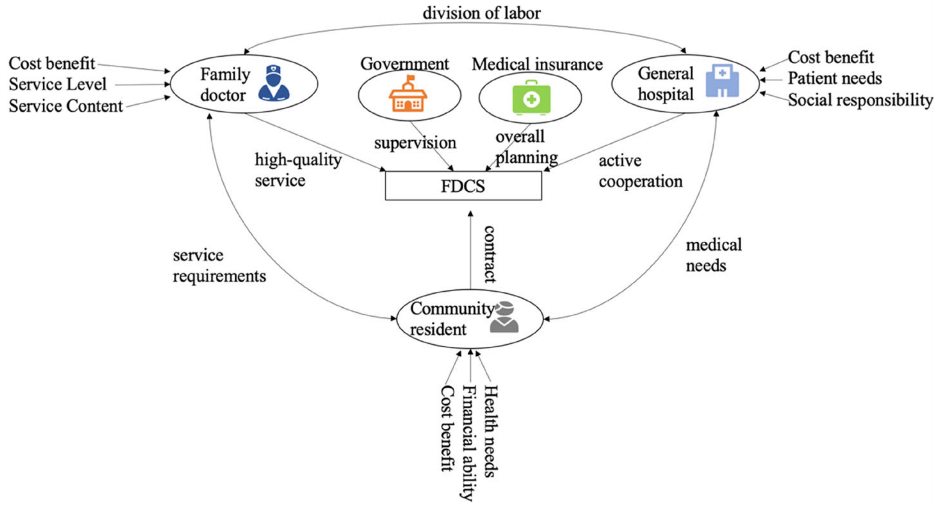


Figure 1. Conceptual model of family doctor service.
Source: news and reports in China.

attitudes involve different levels of effort from the doctor and result in different utilities for the residents. Community residents decide whether to sign a family doctor, as well as what type of service package to choose. When a resident requires medical treatment, uncontracted residents must go to the general hospital directly, while contracted residents can go to the family doctor for the first diagnosis. The family doctor will decide to treat at the grassroots level or transfer to a general hospital. After treatment in general hospitals, contracted residents can be referred to their family doctor for clinical follow-up visits. General hospitals can respond to calls by the government and positively cooperate with family doctors by providing personnel training, support in the discipline, two-way referral priority, and so on. Conversely, a general hospital can pay more attention to its own operations and cooperate negatively with family doctors.

Besides the three core participants of FDS, the government can promote the hierarchical diagnosis system and FDS by providing subsidies to general hospitals or family doctors. The government is also responsible for supervising the operation of hierarchical diagnosis. Furthermore, the medical insurance department has to plan the overall medical insurance fund under the scheme of a hierarchical diagnosis system. Their behaviour also influences decisions of residents, doctors, and hospitals. Overall, we propose the following conceptual model for FDS, shown in Figure 1.

Assumptions and problem setting

We consider a game model consisting of three participants: the resident, family doctor, and general hospital. For convenience, we assume that the family doctor has no income other than the basic salary they get. For simplicity, we assume that the doctor has two options: to provide high-quality (work hard) or low-quality (work less hard) service. All participants have bounded rationality, which means that they alter their decisions during interactions with others. Let the initial proportion of doctors who work hard or work less hard be p and $1-p$, respectively. Similarly, the resident has two options, to sign or not sign a family doctor, with initial proportions q and $1-q$, respectively. A general hospital either positively or negatively cooperates with family doctors, with initial proportions z and $1-z$, respectively.

Service fees for different packages are charged annually for each contracted resident. During the service process, a family doctor receives medical insurance and other public health funds F and government subsidies S after signing a contract with each resident. We assume that the upper limit of slots for each family doctor is N, and the number of residents contracted to the family doctor is n, where $n \leq N$.The costs of the family doctor providing a 'basic service package' and a 'personalised service package' to each contracted resident are c_1 and c_2, respectively, where $c_1 < c_2$. In the cooperation among family doctors and general hospitals, the unit cooperation cost w_f results from medical contract transactions, process procedures, and other factors, while the unit cooperation benefit r_f results from service improvement and residents' trust. Through continuous learning, training, close cooperation with general hospitals, and telemedicine, a family doctor should make additional effort Δc to provide a high-quality service. The government should subsidise family doctors who provide high-quality services with a reward coefficient γ, $\gamma > 1$, to encourage them to work hard, provide better services to residents, induce patients to support their practice, and implement hierarchical diagnosis and treatment. That is, the family doctor who provides high-quality services receives government subsidies γS.[1] The basic salary of the family doctor is I.

For community residents, one must pay an average regular medical cost C_0 each year. When a resident signs a family doctor, they must pay e_1 per year for the basic service package with expected utility V_1 and pay e_2 per year for the personalised service package with expected utility value V_2, where $e_1 < e_2$, $V_1 < V_2$. The proportion of contracted residents who choose to sign the basic service package is θ $(0 \leq \theta \leq 1)$, and $1-\theta$ for the personalised service package. After signing a family doctor, the unit risk is ΔV; it includes the delay in disease diagnosis without timely and effective treatment due to low-quality service of the family doctor or negative cooperation by the general hospital. Community residents who signed family doctors were divided into two groups: general and key populations. General population refers to those whose health issues are mild and whose medical needs can be met by routine medical services provided by family doctors. Key population refers to those whose health conditions may be poor, and who need referrals to a general hospital for further treatment after receiving routine diagnosis and treatment. After this, they return to their family doctors for rehabilitation treatment. The proportion of general and key populations are $1-\tau$ and τ, respectively.

For general hospitals, the unit cost for cooperating with family doctors is w_h, the unit cooperation benefit (including reputation improvement) is r_h, and the unit financial compensation is R. Similarly, in general hospitals, the unit cost for positive cooperation is Δw, and the reward coefficient of financial compensation is ρ, where $\rho > 1$; that is, the actual financial compensation is ρR for general hospitals who choose active cooperation. Family doctors have different influences on the performance and clinical process indicators of the health system. The operating income of general hospitals before the FDS is K. All related parameters are listed in Table 1.

Note that the annual medical expenses of residents will be reduced after signing the contract, and this decrease is affected by the policy support of medical insurance

Table 1. Parameters summary.

Parameter	Definition
F	The medical insurance fund and other financial support received by the family doctor after signing a contract with a community resident
S	The per capita government subsidies for family doctors
N	The maximum number of residents that a family doctor can sign
n	The number of residents contracted by a family doctor
$c_i, i = 1, 2$	The annual cost of the basic or personalised service package provided by family doctors
$e_i, i = 1, 2$	The annual payment of a community resident signing the basic or personalised service package
$V_i, i = 1, 2$	The annual utility of a community resident signing the basic or personalised service package
C_0	The annual medical expenses of a community resident
$\alpha_i, i = 1, 2, 3$	The discount coefficient of the annual medical expenses of a resident when signing a family doctor
$w_i,\ i = f, h$	The unit cooperation cost of family doctors or general hospitals
$r_i,\ i = f, h$	The unit cooperation benefits of family doctors or general hospitals
R	The per capita financial compensation of general hospitals
Δc	The extra unit effort for a family doctor to provide high-quality service
ΔV	The unit risk cost of a community resident due to low-quality service from a family doctor
Δw	The unit effort cost for the positive cooperation of general hospitals
τ	The proportion of key population among contracted residents
m	The referral rate
γ	The government subsidy coefficient for a family doctor who provides high-quality service
ρ	The government financial compensation coefficient for a general hospital with positive cooperation
$I_i, i = 1, 2$	The basic salary received by a family doctor for providing high-quality service or low-quality service
$K_i, i = 1, 2$	The operational benefit that a general hospital obtains from positive or negative cooperation

Note: Unit (year).
Source: news and reports in China.

reimbursement, priority medical treatment, priority referral, and convenient drug dispensing. The discount coefficient is $\alpha_i, i = 1, 2, 3,$ and $0 < \alpha_i < 1$. The value of α_i indirectly reflects the differential payment of medical insurance and the effect of cooperation between family doctors and general hospitals. If the family doctor provides high-quality services and the general hospital chooses to actively cooperate, the community residents' discount coefficient is α_1; if the family doctor chooses to provide low-quality services and the general hospital actively cooperates, or the family doctor chooses to provide high-quality services and the general hospital negatively cooperates, the discount coefficient is α_2; if the family doctor provides low-quality services and the general hospital cooperates passively, the community residents' contract discount coefficient is α_3, where $\alpha_1 < \alpha_2 < \alpha_3$. After the first consultation by the contracted family doctor, the average medical expenses of each contracted resident who receives medical services from a higher-level hospital each year is $\alpha_i C_0$. Among the contracted residents who need to be referred for treatment, if the family doctor provides high-quality services and the general hospital actively cooperates, all are successfully transferred; if the family doctor provides low-quality services or the general hospital cooperates negatively, the actual referral rate is m, where $0 < m < 1$.

Game analysis

According to the analysis of the three participants in the previous chapter, there are eight combinations of strategies under the FDS model, namely {high-quality service—contract—active cooperation}, {high-quality service—contract—negative

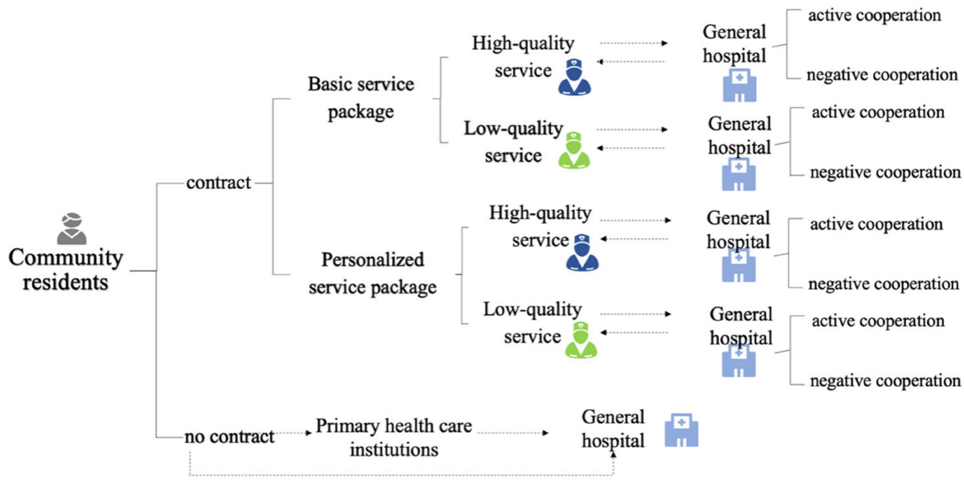


Figure 2. Three-party game tree for family doctor service.
Source: news and reports in China.

Table 2. Payoff Matrix of the Game.

Family doctor	Community resident	General hospital Active cooperation z	 Negative cooperation $1-z$
High-quality service p	Contract q	$I_1+n[F+\gamma S-\Delta c+\Gamma+\tau(r_f-w_f)]$ $\theta(V_1-V_2)+V_2-\alpha_1 C_0$ $K_1+n\tau(r_h-w_h-\Delta w+\rho R)$	$I_1+n[F+\gamma S-\Delta c+\Gamma+\tau m(r_f-w_f)]$ $\theta(V_1-V_2)+V_2-\alpha_2 C_0-\Delta V$ $K_2+n\tau m(r_h-w_h+R)$
	No contract $1-q$	I_1 $-C_0$ K_1	I_1 $-C_0$ K_2
Low quality service $1-p$	Contract q	$I_2+n[F+S+\Gamma+\tau m(r_f-w_f)]$ $\theta(V_1-V_2)+V_2-\alpha_2 C_0-\Delta V$ $K_1+n\tau m(r_h-w_h-\Delta w+\rho R)$	$I_2+n[F+S+\Gamma+\tau m(r_f-w_f)]$ $\theta(V_1-V_2)+V_2-\alpha_3 C_0-\Delta V$ $K_2+n\tau m(r_h-w_h+R)$
	No contract $1-q$	I_2 $-C_0$ K_1	I_2 $-C_0$ K_2

Note: $\Gamma=\theta(e_1-e_2-c_1+c_2)+e_2-c_2$.
Source: news and reports in China.

cooperation}, {high-quality service—no contract—active cooperation}, {high-quality service—no contract—passive cooperation}, {low-quality service—contract—active cooperation}, {low-quality service—contract—passive cooperation}, {low-quality service—no contract—active cooperation}, and {low-quality service—no contract–negative cooperation}. The structure of the game model among family doctors, community residents, and general hospitals is shown in Figure 2, and the payoff matrix is shown in Table 2.

According to the payoff matrix, the expected benefits of family doctors providing 'high-quality' and 'low-quality' services are U_{f1} and U_{f2}, respectively, where

$$\begin{aligned}U_{f1}=&I_1(-1+q)(-1+z)+zI_1-qzI_1+qz(I_1+n(F+\gamma S-\Delta c-\theta c_1\\&+(-1+\theta)c_2+\theta e_1+e_2-\theta e_2+\tau r_f-\tau w_f))\\&+q(1-z)(I_1+n(F+\gamma S-\Delta c-\theta c_1+(-1+\theta)c_2+\theta e_1\\&+e_2-\theta e_2+\tau m r_f-\tau m w_f))\end{aligned} \tag{1}$$

$$U_{f2} = (-1+q)(-1+z)I_2 - (-1+q)zI_2 + qz(I_2 + n(F + \gamma S - \Delta c - \theta c_1 + (-1+\theta)c_2 + \theta e_1 + e_2 - \theta e_2 + \tau m r_f - \tau m w_f)) + q(1-z)(I_2 + n(F + \gamma S - \Delta c - \theta c_1 + (-1+\theta)c_2 + \theta e_1 + e_2 - \theta e_2 + \tau m r_f - \tau m w_f)) \quad (2)$$

The average expected benefit of family doctors is $\bar{U}_f$,

$$\bar{U}_f = n(q+qz-qz)(F+\gamma S-\Delta c) - n(q+qz-qz)\theta c_1 + n(q+qz-qz)(-1+\theta)c_2 + nq\theta e_1 + nqz\theta e_1 - nqz\theta e_1 + nqe_2 + nqze_2 - nqze_2 - nq\theta e_2 - nqz\theta e_2 + nqz\theta e_2 + pI_1 + pqzI_1 - pzI_1 + I_2 - pI_2 + qzI_2 - pqzI_2 - qzI_2 + pqzI_2 + npqz\tau r_f + nq\tau m r_f + nqz\tau m r_f - npqz\tau m r_f - nqz\tau m r_f - npqz\tau w_f - nq\tau m w_f - nqz\tau m w_f + npqz\tau m w_f + nqz\tau m w_f - p(-1+q)zI_1 \quad (3)$$

The expected benefits of community residents who choose 'contract' and 'no contract' are U_{r1} and U_{r2}, respectively, where

$$U_{r1} = (-1+pz)\Delta V + (1+pz-pz)\theta V_1 - (1+pz-pz)(-1+\theta)V_2 - C_0(pz\alpha_1 + \alpha_3 - z((-1+p)\alpha_2 + \alpha_3)) \quad (4)$$

$$U_{r2} = -C_0 \quad (5)$$

The expected benefits of general hospitals choosing 'active cooperation' and 'negative cooperation' are U_{h1} and U_{h2}, respectively, where

$$U_{h1} = K_1 - (\mathrm{n\tau pq} - \mathrm{n\tau m}(-1+p)q)(\Delta\mathrm{w} - \rho\mathrm{R} - r_h + w_h) \quad (7)$$

$$U_{h2} = K_2 + (\mathrm{n\tau pq} - \mathrm{n\tau m}(-1+p)q)(R + r_h - w_h) \quad (8)$$

The average expected return of a general hospital is$\bar{U}_h$,

$$\bar{U}_h = zK_1 - (-1+z)K_2 - (\mathrm{n\tau pq} - \mathrm{n\tau m}(-1+p)q)(R(-1+z) + z(\Delta\mathrm{w} - \rho\mathrm{R}) - r_h + w_h) \quad (9)$$

At the initial stage of strategy selection, there is an unbalanced development among the three parties. However, as the evolution continues, they learn, improve, and constantly alter their own strategies to ensure the most appropriate strategy. The replicator dynamics equation is the process of dynamic adjustment (Fan et al., 2021; Chen et al., 2020). According to the aforementioned expected benefit function, the dynamic replication equation of the tripartite game model of family doctors, community residents, and general hospitals is obtained as follows:

$$\frac{dp}{dt} = F(p) = p\left(U_{f1} - \bar{U}_f\right)$$
$$= -(-1+p)p\left[(1+qz-z)I_1 - I_2 + nqz(\tau - \tau m)(r_f - w_f) - (-1+q)zI_1\right] \quad (10)$$

$$\frac{dq}{dt} = F(q) = q(U_{r1} - \bar{U}_r)$$
$$= (1-q)q(-\Delta V + pz\Delta V + \theta V_1 + V_2 - \theta V_2 - C_0$$
$$\times \{-1 + pz\alpha_1 + \alpha_3 - z[(-1+p)\alpha_2 + \alpha_3]\}) \quad (11)$$

$$\frac{dz}{dt} = F(z) = z(U_{h1} - \bar{U}_h)$$
$$= (-1+z)z[(n\tau pq + n\tau mq - n\tau mpq)(R + \Delta w - \rho R) - K_1 + K_2] \quad (12)$$

To find the equilibrium solution of this evolutionary game, we set simultaneous equations as follows:

$$\begin{cases} F(p) = 0 \\ F(q) = 0 \\ F(z) = 0 \end{cases} \quad (13)$$

By solving Eq. (13), we get eight equilibrium points E_1 $(0,0,0)$, E_2 $(0,1,0)$, E_3 $(1,0,0)$, E_4 $(1,1,0)$, E_5 $(0,0,1)$, E_6 $(0,1,1)$, E_7 $(1,0,1)$, E_8 $(1,1,1)$. These eight equilibrium points constitute the boundary of the solution domain Ω of the evolutionary game model, where $\Omega = \{(p,\ q,\ z)|0 < p < 1,\ 0 < q < 1,\ 0 < z < 1\}$. Simultaneously, there is a ninth equilibrium solution, $E^*(p^*, q^*, z^*)$ that satisfies the above formula in Ω, where

$$p^* = \frac{\Delta V - C_0 - \theta V_1 - pz\theta V_1 - V_2 - pzV_2 + \theta V_2 + pz\theta V_2 + pzC_0\alpha_1 + C_0\alpha_2}{\Delta V - \theta V_1 - V_2 + \theta V_2 + C_0\alpha_2}$$

$$q^* = \frac{-qzI_1 + I_2 + qzI_2 - nqz\tau r_f + nqz\tau m r_f + nqz\tau w_f - nqz\tau m w_f - zI_1}{I_2 - zI_1}$$

$$z^* = 1$$

In an asymmetric game, if the evolutionary game equilibrium E is stable, then E must be a strict Nash equilibrium, which is a pure strategy equilibrium (Selten, 1988). This implies that the mixed-strategy equilibrium in this game must not be an evolutionary stable strategy (ESS). Therefore, we only need to discuss the asymptotic stability of the pure strategy equilibrium. In other words, it is sufficient to analyse the asymptotic stability of the eight pure strategy Nash equilibrium points of E_1 $(0,0,0)$, E_2 $(0,1,0)$, E_3 $(1,0,0)$, E_4 $(1,1,0)$, E_5 $(0,0,1)$, E_6 $(0,1,1)$, E_7 $(1,0,1)$ and E_8 $(1,1,1)$.

According to the method proposed by Friedman (1991), the ESS of the differential equation system can be obtained from the local stability analysis of the Jacobian matrix of the system, which can be obtained from Eqs. (10), (11), and (12).

$$\mathcal{J} = \begin{bmatrix} J_{11} & J_{12} & J_{13} \\ J_{21} & J_{22} & J_{23} \\ J_{31} & J_{32} & J_{33} \end{bmatrix} \tag{14}$$

Where,

$$J_{11} = (1-2p)[(1+qz-z)I_1 - I_2 + nqz(\tau - \tau m)(r_f - w_f) - (-1+q)zI_1]$$

$$J_{12} = -(1-p)pzI_1$$

$$J_{13} = -(1-p)pI_1$$

$$J_{21} = (1-q)qz(\Delta V + C_0\alpha_2)$$

$$J_{22} = (1-2q)(-\Delta V + pz\Delta V + \theta V_1 + V_2 - \theta V_2 - C_0 \times \{-1 + \mathrm{pz}\alpha_1 + \alpha_3 - z[(-1+p)\alpha_2 + \alpha_3]\})$$

$$J_{23} = (1-q)q\{p\Delta V - C_0[(1-p)\alpha_2 - \alpha_3]\}$$

$$J_{31} = (-1+z)z(n\tau q - n\tau mq)(R + \Delta w - \rho R)$$

$$J_{32} = (-1+z)z(n\tau p + n\tau m - n\tau mp)(R + \Delta w - \rho R)$$

$$J_{33} = (2z-1)[(n\tau pq + n\tau mq - n\tau mpq)(R + \Delta w - \rho R) - K_1 + K_2]$$

When the equilibrium point is $\mathrm{E}_1\ (0,0,0)$, then the Jacobian matrix is:

$$\mathcal{J}_1 = \begin{bmatrix} I_1 - I_2 & 0 & 0 \\ 0 & \theta V_1 + (1-\theta)V_2 + (1-\alpha_3)C_0 - \Delta V & 0 \\ 0 & 0 & K_1 - K_2 \end{bmatrix}$$

From this, the eigenvalues of the Jacobian matrix represented by λ are $I_1 - I_2$, $\theta V_1 + (1-\theta)V_2 + (1-\alpha_3)C_0 - \Delta V$ and $K_1 - K_2$respectively. Similarly, the eigenvalues of the Jacobian matrix corresponding to each equilibrium point were obtained by substituting the eight equilibrium points into Eq. (14), as shown in Table 3.

To facilitate the analysis of the eigenvalues corresponding to different equilibrium points without loss of generality, we suppose that $I_1 > I_2$, $\theta V_1 + (1-\theta)V_2 + (1-\alpha_3)C_0 - \Delta V > 0$, $K_2 > K_1$. In other words, in the context of hierarchical diagnosis, the basic salary of family doctors who provide 'high-quality services' is higher than that of those who provide 'low-quality services'. Furthermore, the net utility of community residents who have a 'contract' with a family doctor is greater than those

Table 3. The trace of the equilibrium point.

Point	λ_1	λ_2	λ_3
E_1 $(0,0,0)$	$I_1 - I_2$	$\theta V_1 + (1-\theta)V_2 + (1-\alpha_3)C_0 - \Delta V$	$K_1 - K_2$
E_2 $(0,1,0)$	$I_1 - I_2$	$\Delta V - \theta V_1 - (1-\theta)V_2 - (1-\alpha_3)C_0$	$K_1 - K_2 - n\tau m(R + \Delta w - \rho R)$
E_3 $(1,0,0)$	$I_2 - I_1$	$\theta V_1 + (1-\theta)V_2 + (1-\alpha_3)C_0 - \Delta V$	$K_1 - K_2$
E_4 $(1,1,0)$	$I_2 - I_1$	$\Delta V - \theta V_1 - (1-\theta)V_2 - (1-\alpha_3)C_0$	$K_1 - K_2 - n\tau(R + \Delta w - \rho R)$
E_5 $(0,0,1)$	$I_1 - I_2$	$\theta V_1 + (1-\theta)V_2 + (1-\alpha_2)C_0 - \Delta V$	$K_2 - K_1$
E_6 $(0,1,1)$	$I_1 + n\tau(1-m)(r_f - w_f) - I_2$	$\Delta V - \theta V_1 - (1-\theta)V_2 - (1-\alpha_2)C_0$	$K_2 + n\tau m(R + \Delta w - \rho R) - K_1$
E_7 $(1,0,1)$	$I_2 - I_1$	$\theta V_1 + (1-\theta)V_2 + (1-\alpha_1)C_0$	$K_2 - K_1$
E_8 $(1,1,1)$	$I_2 - I_1 - n\tau(1-m)(r_f - w_f)$	$-[\theta V_1 + (1-\theta)V_2 + (1-\alpha_1)C_0]$	$K_2 + n\tau(R + \Delta w - \rho R) - K_1$

Source: news and reports in China.

Table 4. Result of the analyses of stability in scenario 1 and 2.

	Scenario 1				Scenario 2			
Point	λ_1	λ_2	λ_3	Equilibrium results	λ_1	λ_2	λ_3	Equilibrium results
E_1 $(0,0,0)$	+	+	−	Instable point	+	+	−	Instable point
E_2 $(0,1,0)$	+	−	−	Instable point	+	−	Unknown	Instable point
E_3 $(1,0,0)$	−	+	−	Instable point	−	+	−	Instable point
E_4 $(1,1,0)$	−	−	−	**ESS**	−	−	Unknown	Saddle point
E_5 $(0,0,1)$	+	+	+	Saddle point	+	+	+	Saddle point
E_6 $(0,1,1)$	+	−	+	Instable point	Unknown	−	Unknown	Saddle point
E_7 $(1,0,1)$	−	+	+	Instable point	−	+	+	Instable point
E_8 $(1,1,1)$	−	−	+	Instable point	Unknown	−	Unknown	Saddle point

Source: news and reports in China.

Table 5. Result of analyses of stability in scenario 3 and 4.

Point	Scenario 3				Scenario 4			
	λ_1	λ_2	λ_3	Equilibrium results	λ_1	λ_2	λ_3	Equilibrium results
E_1 $(0,0,0)$	+	+	−	Instable point	+	+	−	Instable point
E_2 $(0,1,0)$	+	−	Unknown	Instable point	+	−	−	Instable point
E_3 $(1,0,0)$	−	+	−	Instable point	−	+	−	Instable point
E_4 $(1,1,0)$	−	−	+	Instable point	−	−	−	**ESS**
E_5 $(0,0,1)$	+	+	+	Saddle point	+	+	+	Saddle point
E_6 $(0,1,1)$	+	−	Unknown	Instable point	Unknown	−	+	Instable point
E_7 $(1,0,1)$	−	+	+	Instable point	−	+	+	Instable point
E_8 $(1,1,1)$	−	−	**Unknown**	**ESS**	Unknown	−	+	Instable point

Source: news and reports in China.

with 'no contract'. Additionally, the operating income of general hospitals with 'active cooperation' is less than that of those with 'negative cooperation'. Due to the complex parameters in the model, the following four situations were considered to examine the stabilization strategy of the game.

Scenario 1: When $r_f > w_f$ and $R + \Delta w - \rho R > 0$; when the community residents choose to sign a contract and the family doctor cooperates with the general hospital, the cooperation benefit of the family doctor is greater than the cooperation cost, and the unit financial compensation for the general hospital's active cooperation is less than the sum of the unit financial compensation and effort cost of passive cooperation.

Scenario 2: when $r_f < w_f$ and $R + \Delta w - \rho R < 0$.

Scenario 3: when $r_f > w_f$ and $R + \Delta w - \rho R < 0$.

Scenario 4: when $r_f < w_f$ and $R + \Delta w - \rho R > 0$.

From Tables 4 and 5, the following theorem can be obtained.

Theorem 1. *When* $r_f > w_f$*and* $R + \Delta w - \rho R > 0$, *the equilibrium point* E_4 $(1, 1, 0)$ *is the only evolutionary stable point. When* $r_f > w_f$ *and* $R + \Delta w - \rho R < 0$, *the equilibrium point* E_8 $(1, 1, 1)$ *is the only evolutionary stable point. When* $r_f < w_f$ *and* $R + \Delta w - \rho R > 0$, *the equilibrium point* E_4 $(1, 1, 0)$ *is the only evolutionary stable point.*

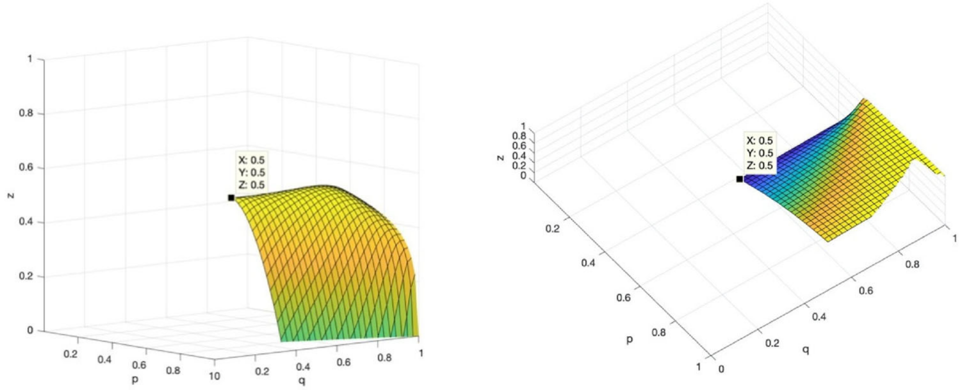
Theorem 1 indicates that when the financial compensation for the general hospital's active cooperation is less than the sum of the financial compensation for their passive cooperation and the cost of effort, i.e., $R + \Delta w - \rho R > 0$, the general hospital will stabilise the adoption of the 'negative cooperation' strategy regardless of whether the cooperation benefit of the family doctor is greater than the cooperation cost. In this case, the dynamic system, which is composed of family doctors, community residents, and general hospitals, is stable at (1,1,0) and represents the strategic combination of {high-quality service-contract-negative cooperation}. However, the promotion of the construction of FDSs under a hierarchical diagnosis and treatment system is inseparable from the joint participation of all key stakeholders. Furthermore, the strategic choice of any key stakeholder will have an impact on the overall effect. At the initial stage of the implementation of FDS in China, due to the lack of support from public hospitals, problems such as low signing rates and non-contract signing are common. The non-cooperation and negative cooperation of general hospitals are not conducive to the implementation of FDSs nor the construction of hierarchical diagnosis. Therefore, only the joint participation of family doctors, community residents, and general hospitals can promote FDS development.

When the cooperation benefit of family doctors is greater than the cost of cooperation, that is, $r_f > w_f$, and the financial compensation for active cooperation of general hospitals is greater than the sum of the financial compensation and effort cost of passive cooperation, that is, $R + \Delta w - \rho R < 0$, family doctors will be stable in adopting the strategy of 'high-quality service', and general hospitals will be stable in adopting an 'active cooperation' strategy. Under these circumstances, the dynamic system composed of family doctors, community residents, and general hospitals is stable in $(1, 1, 1)$, representing the strategy combination of {high-quality service-contract-active cooperation}. This helps FDS become high-quality and improve efficiency, and gradually forms a hierarchical diagnosis pattern.

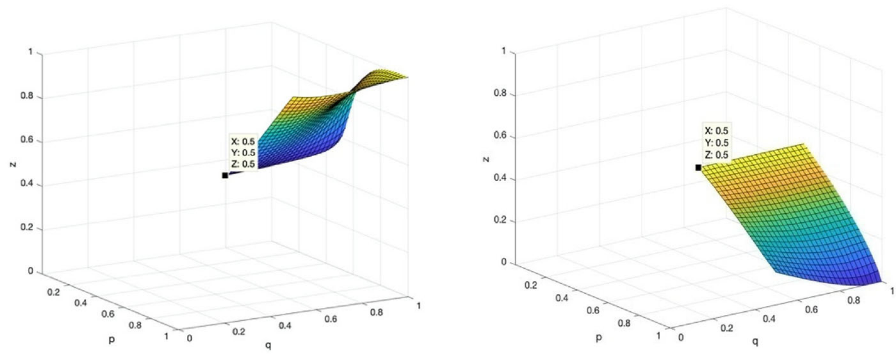
Combining the above analysis, we can see that the development of FDS in China is highly affected by financial incentives for both doctors and general hospitals. However, the financial incentive for general hospitals plays a more important role than that of doctors. Thus, policymakers should focus on inducing general hospitals to promote FDS in China and other similar countries and regions.

Simulation

In the tripartite game model, each participant had referentiality and conformity characteristics. To verify the evolutionary game model and analytical results, we conduct a simulation to explore the trend of the 'family doctor-community residents-general hospital' game model in the previously mentioned four scenarios. The simulation



(a) Scenario 1: $r_f = 200, \rho = 1.2$ (b) Scenario 2: $r_f = 80, \rho = 2$



(c) Scenario 3: $r_f = 200, \rho = 2$ (d) Scenario 4: $r_f = 80, \rho = 1.2$

Figure 3. Evolution of the family doctor service game.
Source: news and reports in China.

Table 6. The simulation parameters' value.

Parameter	p	F	n	α_1	α_2	α_3	e_1	e_2	c_1	c_2	R
Value	0.5	37	2	0.6	0.7	0.8	20	100	50	120	200
Parameter	q	w_f	w_h	C_0	r_h	V_1	V_2	θ	Δc	ΔV	Δw
Value	0.5	100	50	60	300	600	1000	0.3	50	200	60
Parameter	z	τ	m	γ	I_1	I_2	K_1	K_2	S		
Value	0.5	0.4	0.6	1.2	52	42	80	72	30		

Source: news and reports in China.

results of the initial strategy for each subject and the simulation results of the related variables under different values are shown in Figure 3. Except for specific instructions, the values of each parameter are listed in Table 6 (parameter values refer to related news articles[2]). Additionally, the initial willingness to participate in family doctors, community residents, and general hospitals was $p = q = z = 0.5$.

Figure 3 shows the evolutionary trends of the three participants in the four scenarios. The degree of government financial compensation to the general hospital (represented by ρ) directly determines the general hospital's strategic choice. The more compensation there is (in Scenarios 1 and 4), the more actively the general hospital will cooperate. To promote the development of FDS under hierarchical diagnosis and treatment, the ideal situation is that all stakeholders actively participate in the construction of the family doctor system (Scenario 3). Further investigation of Scenario 3 is as follows.

1. The influence of initial intention on the evolution result

Figure 4 shows that regardless of the initial willingness of family doctors, community residents, and general hospitals to participate in FDSs, in Scenario 3, all parties will eventually choose to actively participate in FDSs (blue represents family doctors, red represents community residents, and black represents general hospitals).

2. The impact of per capita financial compensation for general hospitals, R

According to Figure 5, the per capita financial compensation for general hospitals has a decisive effect on the strategic choice of general hospitals but has little impact on family doctors and community residents. The greater the financial compensation, the greater the probability that a general hospital chooses 'active cooperation'. The results show that $R = 50$ is the boundary, leading to different behaviours in a general hospital.

3. The influence of the government's financial compensation coefficient, ρ

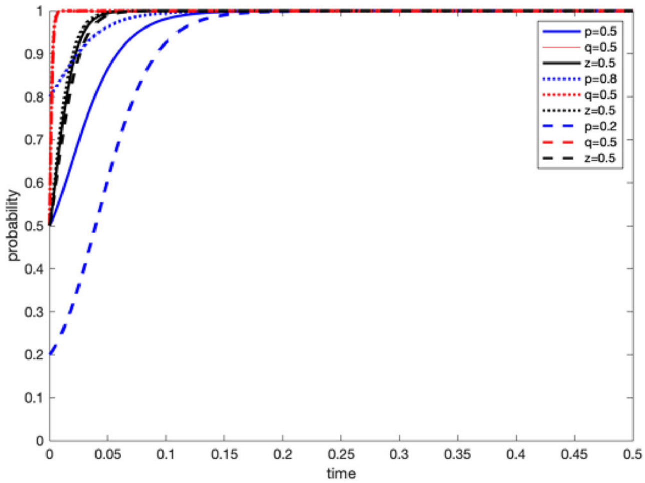
Figure 6 shows that the government's financial compensation coefficient for actively cooperating general hospitals is positively correlated with the probability that general hospitals choose 'active cooperation'. Results show $\rho = 1.25$ is a threshold, which has the same effect as above.

4. Impact of unit effort cost, Δw, required for 'active cooperation' in general hospitals

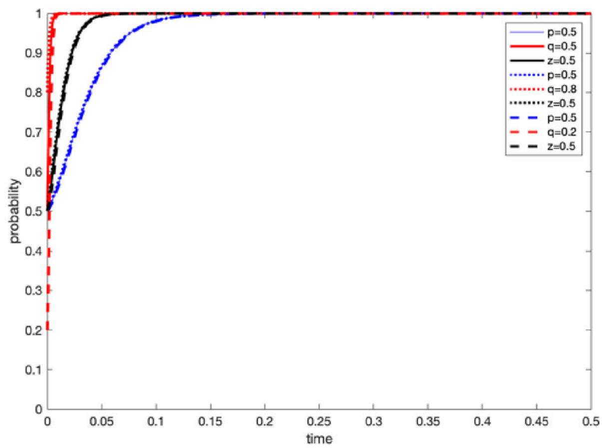
Figure 7 illustrates that the unit effort cost of visiting a general hospital is negatively correlated with the probability of choosing an 'active cooperation' strategy. When $\Delta w < 210$, the general hospital chooses the 'active cooperation' strategy; when $\Delta w > 210$, the general hospital chooses the 'negative cooperation' strategy.

5. Effect of government subsidy incentive coefficient, γ, on the evolutionary results for family doctors who provide high-quality services (Figure 8)

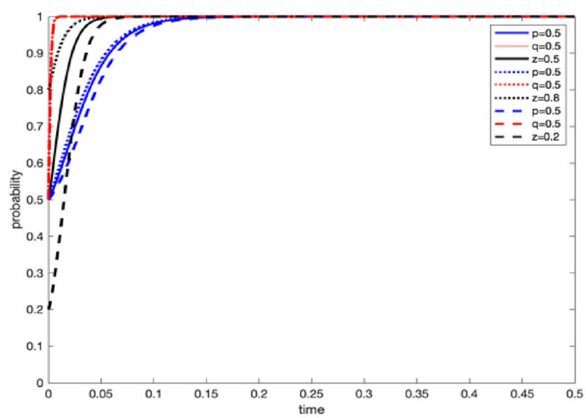
Although the government subsidy incentive coefficient, γ, for family doctors who provide high-quality services changes, the system is always in a stable state.



(a) $q = 0.5, z = 0.5$



(b) $p = 0.5, z = 0.5$



(c) $p = 0.5, q = 0.5$

Figure 4. Influence of different initial proportion of game participants on the evolution.
Source: news and reports in China.

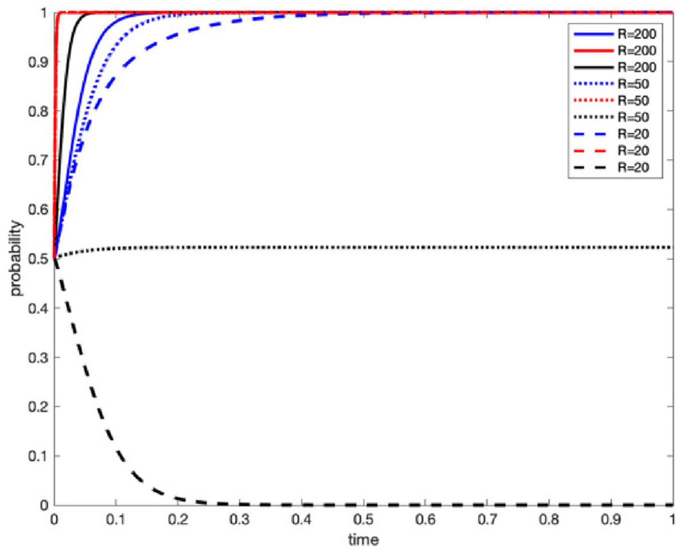


Figure 5. Influence of different initial proportion of game participants on the evolution.
Source: news and reports in China.

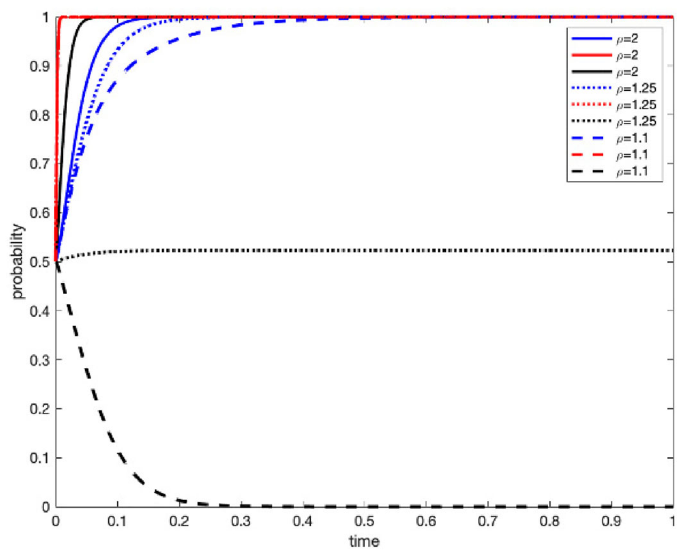


Figure 6. Influence of different initial proportion of game groups on the evolution.
Source: news and reports in China.

Community residents, family doctors, and general hospitals always choose 'contract', 'high-quality service', and 'active cooperation', respectively.

Through the above analysis and comparison, we can draw the following insights.

Corollary 1. Financial incentives play an important role in FDS development in China and in other similar countries and regions.

Corollary 2. The government's financial compensation for general hospitals directly determines the strategic choice of general hospitals. On one hand, the government

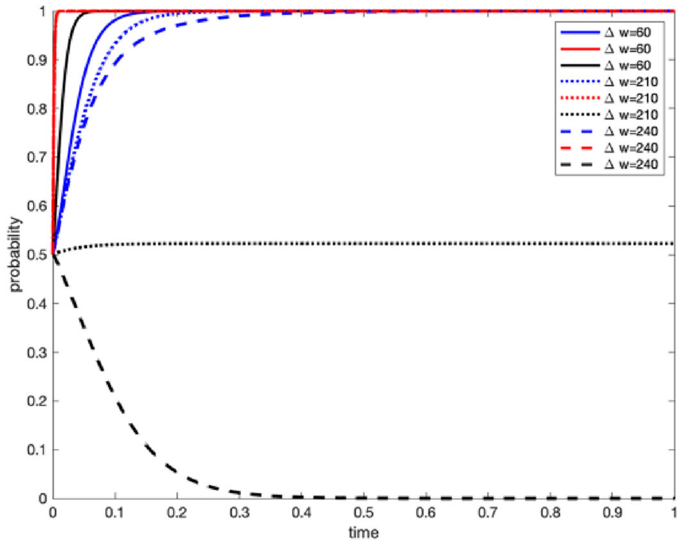


Figure 7. Influence of different initial proportion of game groups on the evolution.
Source: news and reports in China.

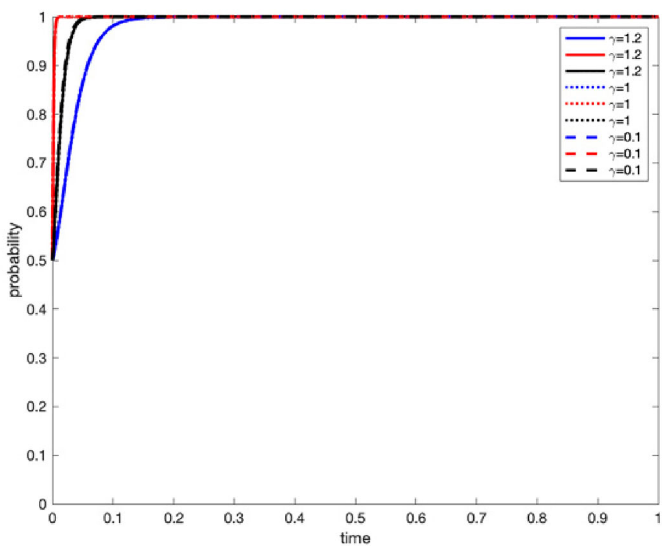


Figure 8. Influence of government's subsidy incentive coefficient γ.
Source: news and reports in China.

should attach more importance to the participation of general hospitals in the construction of FDS and appropriately increase financial subsidies for them. On the other hand, it can reduce the cost of active cooperation with general hospitals by implementing policies and regulations.

Corollary 3. After the initial establishment of the FDS, the government should focus on financial compensation for general hospitals rather than family doctors. Currently, the incentive effect of financial subsidies on family doctors is not significant;

regardless of financial subsidies, family doctors choose to provide a 'high-quality service'. If sufficient financial incentives are provided, the general hospital will actively participate in the game model.

Conclusion

China has made significant progress in strengthening the primary healthcare system; however, the system still faces some challenges, including poor efficiency in the quality of primary healthcare. With the ongoing medical reforms, China can establish a comprehensive and cooperative primary healthcare system based on practice experience and evidence-based theoretical results.

This study established a tripartite evolutionary game model for family doctors, community residents, and general hospitals under bounded rationality to explore the development of FDS in China. We used the replication dynamic equation to solve the nine equilibrium points and analyse their evolutionary stability. We divided the evolution trend into four scenarios and examined the uncertainty and complexity of the implementation of FDSs. We discovered a series of factors that affected the strategic choice of general hospitals, including government subsidies, self-cooperation costs, and reward coefficients. After comparing the government's financial incentives for family doctors and general hospitals, we found that the change in the government's subsidy incentive coefficient, γ, and the government's financial compensation coefficient, ρ, for general hospitals that actively cooperate produced different results. Family doctors have long received strong support and assistance from general hospitals, including human support, information sharing, technical guidance, and two-way referrals. For policymakers to make better use of fiscal funds, it is recommended that more financial subsidies and incentives be given to general hospitals rather than residents. This is because general hospitals play a vital role in promoting the development of FDS under hierarchical diagnosis, and it determines the effectiveness of FDS since it builds trust among residents. With a good foundation for residents and professional support, family doctors will be more motivated to work and continuously improve the quality of service. Additionally, the government should improve the compensation mechanism for contracted service fees and strengthen the development of a talent team for family doctors. Relying on the construction of China's medical alliance, medical institutions should be encouraged to cooperate with family doctors to complement each other. Furthermore, specialised agencies should be organised to conduct regular assessments of family doctors and general hospitals and link performance with salaries and financial subsidies.

The imbalance between the increasing demand for medical services and the limited medical resources indicates that FDS development cannot simply rely on a single group. Only through the joint efforts of family doctors, community residents, general hospitals, and the government, can we promote FDSs and implement a hierarchical diagnosis and treatment system. Our research further provides some management insights and suggestions for policymakers across China and similar countries and regions.

In the post-pandemic era, FDS development in China is critical; thus, we propose a theoretical model for the behaviour of Chinese family doctors under a hierarchical diagnosis and treatment system based on an evolutionary games model. However, corresponding empirical analysis using data from Chinese primary medical and health institutions remains unaddressed, which suggests a possible direction for future research. Since a completely homogeneous group is not always consistent with reality, research on multi-party games under the premise of heterogeneity is another potential research topic.

Disclosure statement

No potential conflict of interest was reported by the authors.

Notes

1. Since it is not easy to identify if a doctor is working hard, this kind of subsidy can be realised in the form of bonuses based on residents' rating.
2. http://www.zjwjw.gov.cn/art/2016/10/18/art_1202194_2411638.html
   http://news.xmnn.cn/xmnn/2019/07/01/100558723.shtml

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