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Research article

Tripartite evolutionary game study on coordination information security in prescription circulation

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Abstract: To further reform the medical and health care system, regulating multi-level treatment and rationalizing the use of medicine, and securing prescription circulation information, this study explores the evolutionary behavior of three players in terms of information security collaboration under the prescription circulation policy, analyzes the evolutionary paths, and examines the influence of key parameters on evolutionary outcomes by constructing a tripartite evolutionary game model consisting of hospitals, retail pharmacies, and healthcare service platforms. The study shows the following: (1) When the information security costs of prescription circulation increase, the willingness of hospitals to promote information collaboration weakens, the probability of control and regulation by healthcare platforms will be enhanced, and the incentive for retail pharmacies to undertake prescription circulation increases and then decreases. (2) The increased profitability of prescription drug sales can cause a decrease in the likelihood of both parties working together to promote information security. Increasing the collaborative space between hospitals and retail pharmacies is conducive to improving information security in the circulation of prescriptions. (3) A bi-directional constraint relationship exists between the circulation and control subjects. The shorter the technology spillover time from the healthcare service platform is, the higher the probability that hospitals and retail pharmacies will maintain the security of prescription information. (4) In the early stages of prescription circulation, the external regulatory action of the healthcare service platform is essential to improve the coordination of information security. Finally, combined with the tripartite evolutionary game model and simulation analysis results, it offers countermeasures and suggestions for the government to realize the prescription circulation information security collaboration.

Keywords: prescription circulation; information security coordination; tripartite evolutionary game; dynamic; simulation analysis

1. Introduction

To deepen the reform of the medical and health system and establish a sound telemedicine service system, China has gradually introduced new policies to promote the process of prescription outflow, aiming to break the mechanism of drug-maintaining-medicine[1], promote medical cost control and graded treatment, and protect patients' autonomy in purchasing medicine [1]. The new model, Internet + medical health, which integrates information security, data sharing, auxiliary infrastructure support and intelligent response, has posed new challenges to the traditional pharmaceutical supply chain [2]. Prescription-sharing platforms have been established in various regions to break down the information barriers between hospitals, pharmacies and health insurance, enabling the vertical extension of the production, supply and marketing of drugs and the horizontal linkage of health consumption services. However, since most of these platforms are capital-driven to launch regional prescription circulation services, the platforms are more concerned about the number of partner healthcare institutions and the feasibility of promoting existing profit models. As a result, the failure of self-regulation of prescription circulation platforms in information security has led to an increased risk of leakage of patient prescription information [3]. The existing regulatory model for prescription circulation is still in the exploration stage. The two-ticket system and the zero-plus-price drug policy have helped reduce the drug ratio and promoted the prescription circulation process to a certain extent [4]. However, the information security and collaboration in the prescription circulation process have not yet been resolved.

Information security collaboration among multiple entities is a comprehensive undertaking where each party needs to define clear boundaries of responsibilities and leverage their respective strengths to safeguard information security collectively. The combination of digital devices and artificial intelligence provides tools to support the realization of medical information sharing, and the traditional diagnostic model faces new changes under information sharing [5]. Existing research on healthcare information security technologies primarily focuses on exploring blockchain technology [6], internal and external element composition [7] and traceability authentication protocols [8]. These technological breakthroughs have provided practical possibilities for enhancing healthcare information security from an application standpoint. Initiating upgrades and optimizations of public healthcare platforms also contributes to equal access to essential healthcare services [9]. However, practical experience reveals that information security issues in the medical field are influenced by a combination of intrinsic driving mechanisms, carrier propulsion and public access mechanisms [10]. Relying solely on technological advancements proves challenging in thoroughly addressing information security collaboration issues. Therefore, achieving information security collaboration should encompass technology considerations, interactive environments, regulatory models, institutional frameworks and other relevant factors. A universal diagnostic framework that utilizes fewer electronic medical records (EMRs) enables the optimization of available healthcare data, improving the persistent shortage and uneven distribution of healthcare resources [11]. In conclusion, to achieve the goal of information security collaboration in prescription circulation, attention should be given to information security vulnerabilities caused by technological deficiencies while considering the depth of cooperation and the level of trust among prescription circulation entities and their impacts on information security collaboration. Existing research often focuses on analyzing the conditions for implementing information security from a technical perspective, with limited studies explicitly addressing the context of prescription circulation and exploring the cross-impact of multiple factors on information security collaboration.

[1] Drug-maintaining-medicine: To increase the revenue of hospital by excessive sales of drugs

Existing research has primarily focused on analyzing the collaborative behavior of supply chain members regarding information security. Sindhuja investigated the impact of information security measures on supply chain stability and performance, demonstrating a positive correlation between information security measures and supply chain stability and performance [12]. Wu et al. demonstrated that the bilateral compensation contract commonly used in the information security outsourcing industry suffers from bilateral moral hazard and is affected by the degree of complementarity among supply chain firms [13]. These results collectively indicate that improving information security conditions is vital in enhancing supply chain efficiency. Additionally, many scholars have applied game theory methods to analyze the collaborative behavior of stakeholders [14,15]. For example, Gu et al. simulated the scenario of a hacker infiltrating two highly interconnected information systems of enterprises, investigating the impact of parameters such as investment efficiency of non-cooperative game situations, contagion risk and hacker learning ability on information system vulnerability [16]. Zhu et al. established an evolutionary game model for patients and mobile healthcare app service providers, studying the behavioral strategies of privacy accountability and compensation between the two parties [17]. Therefore, both domestically and internationally, extensive foundational research has been conducted on achieving information security collaboration among different affiliated entities, whether specific supply chain upstream-downstream relationships or general stakeholder relationships. However, most of these studies explore the general elements of achieving collaborative information security, with few scholars focusing on the heterogeneous elements of information security collaboration in prescription circulation, such as conflicts of interest between hospital pharmacies and retail pharmacies and the trade-offs between prescription encryption costs and circulation benefits.

From the perspective of prescription characteristics, traditional offline channels provide accurate access to prescriptions. However, for patients with chronic diseases, the high cost of regular follow-up visits fails to meet their long-term prescription medication needs. Internet technology has enabled online information synchronization, personalized interventions and monitoring of patient health conditions, while using individual matching databases has made precision treatment possible. Implementing an electronic prescription system generates clear and complete prescriptions, facilitates bi-directional data exchange, improves prescription management efficiency and reduces medication errors [18]. However, the prescription circulation process heavily relies on the stability of software, hardware devices and system operations. Teleconsultation models cannot guarantee the authenticity and professionalism of pharmacists, and physicians often make misdiagnoses and miss diagnoses. Consequently, in practical operations, the rate of medication errors is higher in electronic prescriptions than in paper prescriptions, which indirectly indicates safety hazards in prescription issuance without external regulation. In order to solve this problem, Lu focuses his perspective on the digital technology of residents' healthcare and builds a telemedicine management decision support system, fully considering patients' telemedicine needs and optimizing the relevant modeling elements of the system design [19]. Nevertheless, the information security issue in the prescription flow still needs to be solved, and existing research still needs to address how to ensure the security of prescription circulation information by leveraging the inherent principles of multi-party collaboration. The practical implementation of external prescription circulation faces obstacles and delays that urgently require resolution.

In summary, compared with previous research on medical information security and data sharing, it is found that there are more discussions on the technical implementation of collaborative subjects and information security, but less collaboration is achieved in the process of information security in the process of prescription circulation, as shown in Table 1. Drawing on existing practices in prescription circulation, this study constructs an evolutionary game model consisting of hospitals, retail pharmacies and healthcare service platforms. It proposes an evolutionary path for information security collaboration in prescription circulation and explores the influencing factors and evolutionary trends of strategy choices among the three parties. Numerical simulations analyze the impact of information security collaboration implementation conditions and parameter changes on the evolutionary outcomes during the prescription circulation process. Based on the patterns of evolution and the characteristics of asymptotic stable points, specific recommendations and management strategies are proposed for achieving information security collaboration, aiming to enhance the level of information security collaboration in the prescription circulation process.

Table 1. Collaborative literature statistics on medical information security[2].

Perspective	Typical study	Number
Information security technology	ElRahman & Alluhaidan (2021) [6]	261
	Hassandoust & Subasinghage & Johnston (2022) [7]	
	Ji & Pan & Zhu & He (2023) [20]	
Multi-subject collaboration	Sindhuja (2021) [12]	1054
	Yang &Yang &Chen (2022) [15]	
Prescription circulation process	Roumeliotis & Sniderman & Adams-Webber (2019) [21]	78

2. Model construction

2.1. Problem description

Since the issuance of *The Guiding Opinions on the Reform of Urban Medical and Health Systems* by the State Council Office in 2000, which first proposed the separation of medication and healthcare expenses, separate management, unified submission and reasonable reimbursement, the Chinese government has successively introduced policies to encourage prescription circulation. From local pilot programs to departmental planning, various medical institutions have actively promoted the process of prescription circulation. The typical models of prescription circulation in China include the Wuzhou Model, Fuzhou Model and Yinchuan Model, as described in Table 2. *The Guiding Opinions on Establishing and Improving the Management Mechanism of the National Medical Insurance Negotiation Drug 'Dual Channel'* stipulates implementing a unified payment policy for drugs included in the "dual channel" management. This policy is considered effective in promoting the implementation of prescription circulation. Fujian province has taken the lead in implementing the "dual channel" electronic prescription circulation service. Therefore, the "Hospital-Retail Pharmacy-Healthcare Service Platform" model proposed in this study aligns with the practical logic of the Fuzhou Model.

Hospitals issue prescriptions to repeat patients and upload them to the healthcare services platform, where retail pharmacies can obtain electronic prescriptions and provide prescription drugs to patients. The hospital is the outgoing end of the prescription, and the retail pharmacy is the receiving end, with the two entities deciding whether to collaborate and take over. The information security of prescriptions is related to patients' privacy, hospitals' social reputation and the accuracy of retail pharmacies' drug selection, and the medical service platform acts as a circulation medium to determine

[2] Date Source: China National Knowledge Infrastructure (CNKI) search data, 2023/10/12

whether to control the information security. As a result, for the study, we construct a tripartite game model logic relationship, as shown in Figure 1.

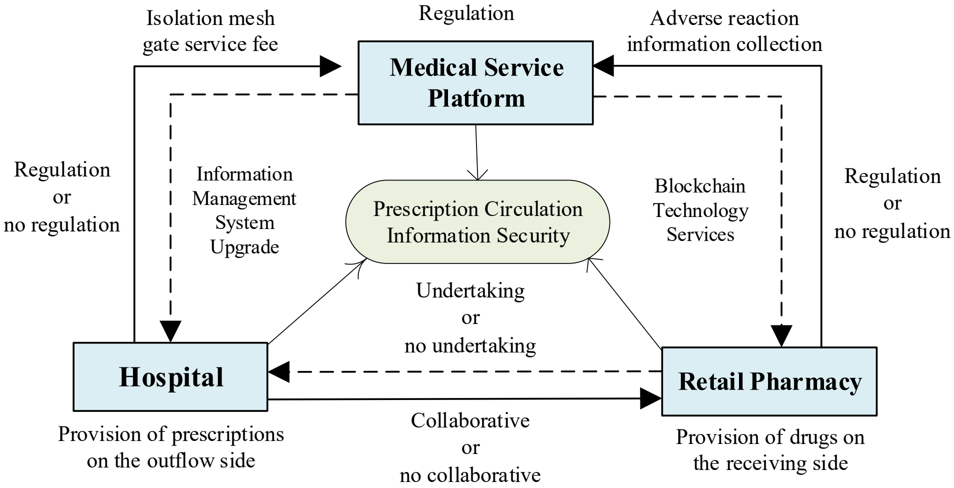

Figure 1. Logic diagram of the tripartite game model.

Table 2. Typical domestic prescription circulation practices[3].

Model	Policy documents	Specific description
Wuzhou Model	*Notice on Issues Relating to the Trial Implementation of Direct Settlement of Outpatient Special Chronic Diseases under the Health Insurance Scheme in Prescription Sharing Pharmacies*	In order to enhance collaboration among medical institutions, medical insurance settlement, and pharmaceutical retail, secondary hospitals and retail pharmacies have jointly connected to a third-party platform for easy re-visits, enabling the realization of a "Tripartite Collaboration" system.
Fuzhou Model	*Notice on the Issuance of the Pilot Program for Electronic Prescription circulation in Fuzhou*	Focusing on entity public hospitals, we have established the fundamental principles of prescription sharing platforms, "dual" prescription review with retail pharmacies and a "unanimous veto" exit mechanism. Doctors issue prescriptions, which pharmacists review before uploading to the prescription-sharing platform. With the launch of the "two-way" service, patients are empowered to independently purchase medications from external sources.
Yinchuan Model	*Yinchuan Internet Treatment Service Specification*	This document highlights the government's investment in constructing a public prescription circulation platform and developing the Yinchuan Health Square mini program. The platform serves as a centralized system for coordinating and optimizing the allocation of medical resources, facilitating seamless information exchange and enhancing collaboration among various healthcare stakeholders.

[3] Source: Fuzhou, Yinchuan and Wuzhou Health Commission

2.2. Model hypotheses

***H1*: **Set up a tripartite gaming body for hospitals, retail pharmacies and medical service platforms. The supply and demand of prescription drugs are balanced, and the application rate of e-prescriptions by patients is 100%. Players' behavior in the game is based on the principle of limited rationality, and the evolutionary results tend to be stable strategies.

***H2*: **Hospital strategy space α=(collaborative, no collaborative), the probability of adopting a collaborative strategy is x, and the probability of adopting a non-collaborative strategy is $1-x$. Retail pharmacy strategy space β=(undertaking, no undertaking), the probability of adopting an undertaking strategy is y, and the probability of adopting a non-undertaking strategy is $1-y$. Health service platform strategy space γ=(regulation, no regulation), the probability of adopting a regulation strategy is z, and the probability of adopting a non-regulation strategy is $1-z$. $x, y, z \in [0,1]$.

***H3*: **The government regulator collects the performance bond for the information security of prescription circulation. Hospitals, retail pharmacies and health service platforms pay shares θ, ω and φ, respectively, and $\theta+\omega+\varphi=1$ is required to ensure. If the hospital does not collaborate, and the retail pharmacy does not take over, the circulation of prescriptions cannot be achieved, and all three parties will pay no deposit.

***H4*: **Under the "dual access" policy, both hospitals and retail pharmacies sell prescriptions at a profit of π_{hp}. In order to achieve secure internal and external data interaction, the healthcare service platform provides isolated gate services to hospitals, and hospitals pay for the application cost C_h. When hospitals do not collaborate, they will sell drugs directly to patients through the in-hospital pharmacy, and prescription circulation is not possible, so hospitals do not need to pay for isolated gate services for prescription data interaction. The hospital does not need to pay for the isolated gate service for prescription data interaction.

***H5*: **Retail pharmacies make a profit on the sale of over-the-counter drugs L_n. When taking over prescriptions, retail pharmacies upload information on adverse drug reactions collected through the medical services platform to provide hospital physicians with advice on the use of prescription drugs S. At the same time, in order to achieve encryption of prescription data, the taking over retail pharmacies should pay the medical services platform for the cost of blockchain technology services π_l. If retail pharmacies do not take over the circulation of prescriptions, there is no such income or expenditure.

***H6*: **Medical service platform information maintenance costs are C_p. Under the control strategy, the medical service platform provides hospital management information system (HIS) upgrade and platform docking services to hospitals with a willingness to collaborate to improve the information security management capabilities of hospital prescriptions π_v; at the same time, the medical service platform issues signature keys and provides certificate authority (CA) real-name authentication services to the retail pharmacies it undertakes to enhance the security of prescription drug sales L_p. According to the *State Supervision and Administration of Network Transactions* published by the General Administration of Market Regulation, if the medical service platform knows or should know that the prescription circulation process has significant hidden dangers but does not control it, it should be jointly and severally liable with the infringing subject according to law and the medical service platform social reputation loss R.

We consider the information security collaboration of prescription circulation in a tripartite game and construct a tripartite game payment matrix according to the hypotheses, as shown in Table 3.

Table 3. Hospital-retail pharmacy-medical service platform triple play payment matrix.

	Collaboration		No collaboration	
	Undertaking	No undertaking	Undertaking	No undertaking
Regulation	$S-\theta C_s-C_h-\pi_{hp}+\pi_v$	$-C_h-\theta C_s+\pi_v+\pi_{hp}$	$\pi_{hp}+S$	π_{hp}
	$L_n+\pi_{hp}-\omega C_s-\pi_l+L_p$	L_n	$L_n-\omega C_s+L_p-\pi_l$	L_n
	$-C_p-\varphi C_s+C_h+\pi_l$	$-C_p+C_h-\varphi C_s$	$\pi_l-C_p-\varphi C_s$	$-C_p$
No regulation	$S-\theta C_s-\pi_{hp}$	$-\theta C_s+\pi_{hp}$	$\pi_{hp}+S$	π_{hp}
	$L_n+\pi_{hp}-\omega C_s-\pi_l$	L_n	$L_n-\omega C_s-\pi_l$	L_n
	$-C_p-\varphi C_s+\pi_l-R$	$-C_p-\varphi C_s-R$	$\pi_l-C_p-\varphi C_s-R$	$-C_p$

3. Analysis of the strategic choice stability

3.1. Hospital strategy stability analysis

The expected return E_{11} for the hospital circulation strategy, the expected return E_{12} for the no circulation strategy and the average expected return $\overline{E_1}$ are as follows:

$$\begin{aligned} E_{11} &= yz(S-\theta C_s-C_h-\pi_{hp}+\pi_v)+y(1-z)(S-\theta C_s-\pi_{hp}) \\ &+(1-y)z(-C_h-\theta C_s+\pi_v+\pi_{hp})+(1-y)(1-z)(-\theta C_s+\pi_{hp}) \end{aligned} \tag{1}$$

$$E_{12} = yz(\pi_{hp}+S)+y(1-z)(\pi_{hp}+S)+(1-y)z\pi_{hp}+(1-y)(1-z)\pi_{hp} \tag{2}$$

$$\overline{E_1} = xE_{11}+\left(1-x\right)E_{12} \tag{3}$$

The replication dynamic equations and x first-order derivatives of the hospital's implementation of the circulation strategy are shown in Eqs (4) and (5), and setting $A(y,z)$ is shown in Eq (6):

$$F\left(x\right)=\frac{dx}{dt}=x\left(E_{11}-\overline{E_1}\right)=x\left(1-x\right)\left(\pi_v z-C_h z-2\pi_{hp}y-\theta C_s\right) \tag{4}$$

$$\frac{\partial F(x)}{\partial x}=(1-2x)\left(\pi_v z-C_h z-2\pi_{hp}y-\theta C_s\right) \tag{5}$$

$$A(y,z)=\pi_v z-C_h z-2\pi_{hp}y-\theta C_s \tag{6}$$

Proposition 1: Let $y^* = -(\theta C_s + C_h z - \pi_v z)/2\pi_{hp}$. If $y < y^*$, the hospital uses collaboration as its stabilization strategy; if $y > y^*$, the hospital uses no collaboration as its stabilization strategy; if $y = y^*$, its stabilization strategy cannot be determined.

***Proof of Proposition* 1**: $\partial A(y,z)/\partial y < 0$, and $A(y,z)$ is a decreasing function on y. If $y < y^*$, $A > 0$ and $\partial F(x)/\partial x|_{x=1} < 0$, $x = 1$ is the hospital stable strategy; if $y > y^*$, $A < 0$ and $\partial F(x)/\partial x|_{x=0} < 0$, then $x = 0$ is the hospital stable strategy; if $y = y^*$, $\partial F(x)/\partial x = 0$, the hospital cannot determine the stable strategy, where $y^* = -(\theta C_s + C_h z - \pi_v z)/2\pi_{hp}$.

According to this proposition, an evolutionary phase diagram of the hospital strategy can be obtained, as shown in Figure 2.

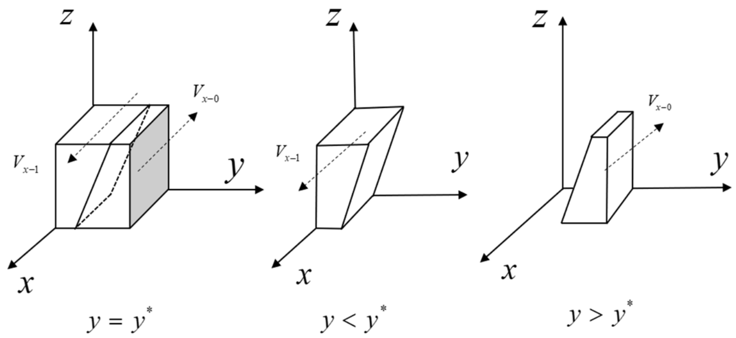

Figure 2. Phase diagram of the evolution of hospital strategies.

From Figure 2, V_{x-0} is the probability space for the hospital's non-cooperative strategy, and V_{x-1} is the probability space for the hospital's cooperative strategy, calculated as follows:

$$V_{x-0} = \int_0^1 \int_0^{\frac{-\theta C_s}{C_h - \pi_v}} \frac{-(\theta C_s + C_h z - \pi_v z)}{2\pi_{hp}} dxdz = \frac{(\theta C_s)^2}{4\pi_{hp}(C_h - \pi_v)} \tag{7}$$

$$V_{x-1} = 1 - V_{x-0} = 1 - \frac{(\theta C_s)^2}{4\pi_{hp}(C_h - \pi_v)} \tag{8}$$

Corollary 1.1 The higher the profitability of prescription drug sales is, the higher the probability of hospital collaboration when the hospital bears a small amount of the prescription circulation information security performance margin. When the healthcare service platform is controlled, the probability of hospital collaboration decreases as the hospital's prescription information security management capability improves, and the cost of isolated mesh gate application decreases.

***Proof of Corollary* 1.1**: $\partial V_{x-1}/\partial \pi_{hp} > 0$, $\partial V_{x-1}/\partial(\pi_v - C_h) < 0$. Since $(\theta C_s)^2 > 0$ is constant, V_{x-1}

decreases as the absolute value of V_{x-1} increases.

Hospitals are more motivated to promote prescription circulation when they are responsible for a smaller performance bond for the safe circulation of prescriptions. The greater the profitability of prescription drug sales, the greater the willingness of retail pharmacies to take over, and the greater the potential revenue for hospitals through "hospital-store collaboration" are, the greater the potential for hospital information collaboration. In addition, the better the hospital's ability to manage the security of prescription information is, the lower the risk of information security for in-hospital drug purchases and the higher the level of patient privacy protection. Under the guarantee of the "dual-channel medical insurance" unified payment policy, the uniform purchase price of prescription drugs has eliminated patients' price concerns, and the convenience of in-hospital drug purchase has made patients more inclined to purchase prescription drugs in-hospital. In this scenario, hospitals will be more motivated to improve the information security of their HIS systems. In contrast, the motivation to promote information security will gradually weaken, and the resistance to the circulation of prescriptions will increase.

Corollary 1.2 The interest relationship between the healthcare service platform and the hospital influences the retail pharmacy's strategy choice. If the cost paid by the hospital for the segregated gateway service is greater than the benefit derived from its increased ability to manage the security of prescription information, the probability of retail pharmacies not taking it on increases; conversely, retail pharmacies tend to adopt a take-up strategy.

***Proof of Corollary* 1.2:** $\partial y^* / \partial z = \pi_v - C_h (s.t.\ \pi_v - C_h \neq 0)$. If $\pi_v < C_h$, y^* is a decreasing function on z. From Proposition 1, if $y < y^*$, hospitals adopt a collaborative strategy, threshold y^* decreases as z increases and y tends to decrease, and the retail pharmacy chooses to implement a no-take strategy. If $\pi_v > C_h$, y^* is an increasing function on z. The same can be proved, as threshold y^* increases as z increases and y tends to increase, and the retail pharmacy choose to implement an off-take strategy.

Suppose the gain in HIS system optimization services provided by the healthcare service platform cannot compensate for the cost of isolated gate services spent by hospitals. In that case, hospitals will obtain fewer technology spillover benefits and will reduce their investment in information collaboration to reverse the negative profitability in the future period. After the probability of hospital collaboration is reduced, the poor circulation of prescriptions will result in less revenue for retail pharmacies to undertake, and the willingness of retail pharmacies to continue to undertake will gradually weaken. Retail pharmacies' reduced likelihood of take-up at this time is influenced by the prescription outflow restrictions of hospitals rather than the autonomous decisions taken by retail pharmacies following revenue judgements.

3.2. Retail pharmacy strategy stability analysis

The expected return E_{21} for the retail pharmacy take-up strategy, the expected return E_{22} for the non-take-up strategy and the average expected return $\overline{E_2}$ are as follows:

$$E_{21} = xz(L_n + \pi_{hp} - \omega C_s - \pi_l + L_p) + x(1-z)(L_n + \pi_{hp} - \omega C_s - \pi_l)$$
$$+(1-x)z(L_n - \omega C_s + L_p - \pi_l) + (1-x)(1-z)(L_n - \omega C_s - \pi_l) \quad (9)$$

$$E_{22} = xzL_n + x(1-z)L_n + (1-x)L_n + (1-x)(1-z)L_n \quad (10)$$

$$\overline{E_2} = yE_{21} + (1-y)E_{22} \quad (11)$$

The replication dynamic equation and y first order derivative of the take-up strategy adopted by the retail pharmacy are shown in Eqs (12) and (13), and set $B(x,z)$ as shown in Eq (14):

$$F(y) = \frac{dy}{dt} = y\left(E_{21} - \overline{E_2}\right) = y(1-y)\left(-\pi_l - \omega C_s + L_p z + \pi_{hp} x\right) \quad (12)$$

$$\frac{\partial F(y)}{\partial y} = (1-2y)\left(-\pi_l - \omega C_s + L_p z + \pi_{hp} x\right) \quad (13)$$

$$B(x,z) = -\pi_l - \omega C_s + L_p z + \pi_{hp} x \quad (14)$$

Proposition 2: Let $z^* = (\pi_l + \omega C_s - \pi_{hp} x) / L_p$. If $z < z^*$, the retail pharmacy takes no take-up as its stabilization strategy; if $z > z^*$, the retail pharmacy takes take-up as its stabilization strategy; if $z = z^*$ then it is not possible to determine its stabilization strategy.

***Proof of Proposition* 2**: $\partial B(x,z)/\partial z > 0$, and $B(x,z)$ is a increasing function on z. If $z < z^*$, $B(x,z) < 0$ and $\partial F(y)/\partial y|_{y=0} < 0$, $y = 0$ is the retail pharmacy stable strategy; if $z > z^*$, $B(x,z) > 0$ and $\partial F(y)/\partial y|_{y=1} < 0$, then $y = 1$ is the retail pharmacy stable strategy; if $z = z^*$, $\partial F(y)/\partial y = 0$, the retail pharmacy cannot determine the stable strategy, where $z^* = (\pi_l + \omega C_s - \pi_{hp} x) / L_p$.

According to this proposition, a phase diagram of the evolution of retail pharmacy strategies can be obtained, as shown in Figure 3.

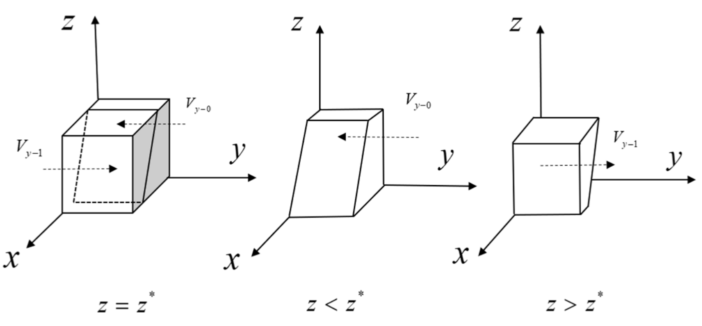

Figure 3. Phase diagram of the evolution of retail pharmacy strategies.

From Figure 3, V_{y-0} is the probability space for retail pharmacies not to take over, and V_{y-1} is the probability space for retail pharmacies to take over, calculated as follows:

$$V_{y-0} = \int_0^1 \int_0^{\frac{\pi_l + \omega C_s}{\pi_{hp}}} \frac{\pi_l + \omega C_s - \pi_{hp} x}{L_p} dxdy = \frac{(\pi_l + \omega C_s)^2}{2L_p \pi_{hp}} \tag{15}$$

$$V_{y-1} = 1 - V_{y-0} = 1 - \frac{(\pi_l + \omega C_s)^2}{2L_p \pi_{hp}} \tag{16}$$

Corollary 2.1 To safeguard the circulation of prescription information, the healthcare service platform will increase its control when both the willingness of retail pharmacies to take up and the willingness of hospitals to collaborate are low.

***Proof of Corollary* 2.1**: $\partial z^* / \partial x < 0$, and z^* is a decreasing function on x. From Proposition 2, if $z < z^*$, the retail pharmacy takes a no take-up strategy, threshold z^* decreases as x increases and z tends to decrease, and health service platforms choose not to regulate as strategy.

The availability of patient prescription information increases when hospitals promote collaborative prescription circulation information. Hospitals' concern for the security of prescription information circulation decreases as their willingness to collaborate wanes, and if retail pharmacies do not take over now, they cannot ensure the security of prescription information circulation. For this reason, healthcare service platforms must play a full regulatory role to ensure that the entire process of prescription information system operation is traceable and improve the security of existing prescription circulation information. In addition, the profit-driven participation of the outflow side and the receiving side in the circulation of prescriptions will play an effective role in self-regulation on both sides, positively strengthening the self-regulatory behavior of hospitals and retail pharmacies in terms of the security of prescription circulation information, which is also a useful complement to the control model of the healthcare service platform.

Corollary 2.2 The probability of retail pharmacies taking up the strategy rises with the willingness of hospitals to collaborate and the increased control of healthcare service platforms.

***Proof of Corollary* 2.2**: If $x < (\pi_l + \omega C_s - L_p z) / \pi_{hp}$, $B(x,z)$ and $\partial F(y) / \partial y |_{y=0} < 0$, $y = 0$ is the retail pharmacy stable strategy; on the contrary, $y = 1$ is the retail pharmacy stable strategy. As x and z increase, the stabilization strategy of the retail pharmacy evolves from $y = 0$ to $y = 1$.

The hospitals give positive signals on the circulation of prescriptions, and healthcare service platforms provide external protection for prescription information security through regulatory means. Under such circumstances, hospitals will invest more in prescription information security to enhance collaboration's overall effectiveness and revenue. The secure circulation environment created by the outflow side and the circulation medium will help retail pharmacies increase their take-up revenue, and retail pharmacies will be motivated to do so.

Corollary 2.3 Relying on signature keys and CA real-name authentication technology, the higher the security of prescription drug sales is, the greater the probability of retail pharmacies taking over.

The more significant the sum of the cost of blockchain technology and the share of the security performance bond for the circulation of prescription information is, the lower the probability of retail pharmacies taking over.

***Proof of Corollary* 2.3:** $\partial V_{y-1} / \partial L_p > 0$ and $\partial V_{y-1} / \partial \pi_{hp} > 0$. Since $(\pi_l + \omega C_s)^2 > 0$ is constant, V_{x-1} decreases as the absolute value of $\pi_l + \omega C_s$ increases.

The provision of blockchain technology services by medical service platforms is conducive to increasing the probability of take-up by retail pharmacies. At the same time, the expenditure on prescription information security will weaken the incentive of take-up by retail pharmacies. Therefore, the potential revenue from retail pharmacies' information security maintenance costs is within a reasonable range; the medical service platform makes full use of blockchain technology to expand the application scenario of "module linkage" and bring into play the technology spillover effect. To ensure information security, we will expand pharmacy cooperation channels and explore the pharmacy benefit management (PBM) model to enhance the willingness of retail pharmacies to take over.

3.3. Healthcare service platform strategies stability analysis

The expected return E_{31} for the health services platform control strategy, the expected return E_{32} for the no control strategy and the average expected return $\overline{E_3}$ are as follows:

$$\begin{aligned} E_{31} &= xy(-C_p - \varphi C_s + C_h + \pi_l) + x(1-y)(-C_p + C_h - \varphi C_s) \\ &+ (1-x)y(\pi_l - C_p - \varphi C_s) - (1-x)(1-y)C_p \end{aligned} \tag{17}$$

$$\begin{aligned} E_{32} &= xy(-C_p - \varphi C_s + \pi_l - R) + x(1-y)(-C_p - \varphi C_s - R) \\ &+ (1-x)y(\pi_l - C_p - \varphi C_s - R) - (1-x)(1-y)C_p \end{aligned} \tag{18}$$

$$\overline{E_3} = zE_{31} + \left(1 - z\right)E_{32} \tag{19}$$

The replicated dynamic equations and z first-order derivatives for the choice of control strategy for the health services platform are shown in Eqs (20), (21), setting $C(x, y)$ as shown in Eq (22):

$$F(z) = \frac{dz}{dt} = z(E_{31} - \overline{E_3}) = z\left(1 - z\right)\left(C_h x + Rx + Ry - Rxy\right) \tag{20}$$

$$\frac{\partial F(z)}{\partial z} = (1 - 2z)\left(C_h x + Rx + Ry - Rxy\right) \tag{21}$$

$$C(x, y) = C_h x + Rx + Ry - Rxy \tag{22}$$

Proposition 3: Let $x^* = -Ry / \left(C_h + R - Ry\right)$. If $x < x^*$, the health services platform takes no control as its stabilization strategy; if $x > x^*$, the health services platform takes control as its stabilization strategy; if $x = x^*$ then it is not possible to determine its stabilization strategy.

***Proof of Proposition* 3**: $\partial C(x,y)/\partial x > 0$, and $C(x,y)$ is an increasing function on x. If $x < x^*$, $C(x,y) < 0$ and $\partial F(z)/\partial z|_{z=0} < 0$, $y = 0$ is the retail pharmacy stable strategy; if $z > z^*$, $C(x,y) > 0$ and $\partial F(z)/\partial z|_{z=1} < 0$, then $y = 1$ is the retail pharmacy stable strategy; if $z = z^*$, $\partial F(z)/\partial z = 0$, the health services platform cannot determine the stable strategy, where $x^* = -Ry/\left(C_h + R - Ry\right)$.

According to this proposition, an evolutionary phase diagram of the healthcare service platform strategy can be obtained, as shown in Figure 4.

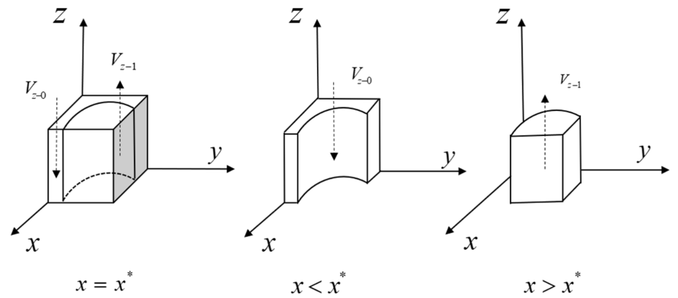

Figure 4. Phase diagram of the evolution of healthcare service platform strategies.

From Figure 4, V_{z-0} is the probability space for a healthcare delivery platform to be unregulated, and V_{z-1} is the probability space for a healthcare delivery platform to be regulated, calculated as:

$$V_{z-0} = \int_0^1\int_0^1 \frac{-Ry}{C_h + R - Ry} dydz = 1 - \frac{-C_h - R}{C_h + R - Ry} = 1 - \frac{C_h + R}{R}\ln\frac{C_h}{C_h + R} \tag{23}$$

$$V_{z-1} = 1 - V_{z-0} = (1 + \frac{C_h}{R})\ln(1 - \frac{R}{C_h + R}) \tag{24}$$

Corollary 3.1 When hospitals collaborate, the incentive to control healthcare service platforms rises as the revenue from the isolated gate service increases.

***Proof of Corollary* 3.1**: Since $-\frac{R}{C_h} < \ln(1 - \frac{R}{C_h + R}) < -\frac{R}{C_h + R} (s.t.\ R(C_h + R) < 0)$, $\partial V_{z-1}/\partial C_h > 0$.

The more revenue the healthcare service platform obtains from the segregated gate service, the greater the regulatory input of the healthcare service platform will be. Profit maximization-oriented third-party organizations are capital-driven, so a healthcare service platform that relies solely on the participation of third-party organizations in its construction cannot guarantee the long-term security and stability of the circulation of prescription information. Therefore, it should adhere to the government leadership, give full play to the third party's technical support for information security, and avoid the occurrence of rent-seeking behavior under authorized regulation.

Corollary 3.2 The probability of simultaneous hospital collaboration and retail pharmacy take-up decreases when the incentive to regulate health service platforms is weakened.

***Proof of Corollary* 3.2:** $\partial x^* / \partial y < 0$, and x^* is an increasing function on y. From Proposition 3, if $x < x^*$, health service platforms choose not to regulate as a strategy, and threshold x^* decreases as y increases and x tends to decrease.

As external constraints are relaxed, the security performance margin for prescription information circulation borne by healthcare service platforms is passed on to hospitals and retail pharmacies, and the profitability of prescription drug sales increases the instability of the positive-sum game between hospitals and retail pharmacies. At the same time, the security of prescription information circulation decreases as the probability of control by healthcare service platforms decreases, and the willingness of both the outgoing and incoming sides to promote prescription circulation decreases.

4. Stability analysis of strategic combination

Letting $F(x) = F(y) = F(z) = 0$, we obtain that there exist 8 pure strategy equilibrium solutions and 1 mixed strategy equilibrium solution for the replicated dynamic equation system, $E_1(0,0,0)$, $E_2(1,0,0)$, $E_3(0,1,0)$, $E_4(0,0,1)$, $E_5(1,1,0)$, $E_6(1,0,1)$, $E_7(0,1,1)$, $E_8(1,1,1)$ and $E_9(x_1, y_1, z_1)$, respectively. It has been demonstrated that the stable solution of a multi-group evolutionary game must be a strict Nash equilibrium solution. Thus, the study will analyze the stability of eight pure strategy equilibrium points. The eigenvalues of the equilibrium solutions are found by the Jacobian matrix equation of the 3D dynamical system, as in Table 4.

$$J = \begin{pmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} & \frac{\partial F(x)}{\partial z} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} & \frac{\partial F(y)}{\partial z} \\ \frac{\partial F(z)}{\partial x} & \frac{\partial F(z)}{\partial y} & \frac{\partial F(z)}{\partial z} \end{pmatrix}$$

$$= \begin{pmatrix} (2x-1)(C_h z + 2\pi_{hp} y + \theta C_s - \pi_v z) & 2\pi_{hp} x(x-1) & (C_h - \pi_v) x(x-1) \\ y(1-y)\pi_{hp} & (2y-1)(\pi_l + \omega C_s - L_p z - \pi_{hp} x) & L_p y(1-y) \\ (1-z)z(C_h + R - Ry) & R(x-1)z(z-1) & (1-2z)(C_h x + Rx + Ry - Rxy) \end{pmatrix}$$

Situation 1 The $E_1(0,0,0)$ saddle point indicates that hospitals do not collaborate, retail pharmacies do not undertake, and medical service platforms do not control. Hospitals maintain the profitability of prescription drug sales in their pharmacies through the non-cooperation strategy and adhere to the traditional model of driving high hospital revenue with high profitability of prescription drugs. The performance deposit for the information security circulation of prescriptions also plays a hindering role in hospital information collaboration, and the hospital's share of the ratio directly affects the difficulty of prescription outflow; retail pharmacies maintain their existing drug sales based on their weak capacity to take over, pilot policy limitations and patients' inertia in accessing medicine. At the same time, compared to the high cost of blockchain technology services, retail pharmacies have a lower degree of improvement in the security of prescription drug sales, and the retail pharmacies will not have a high return on investment in the security of prescription information after taking over and will not be willing to take over; when the circulation of prescriptions has not reached both ends of the outflow and taking over, the probability of the medical service platform intervening to control the initial state is low. This saddle point explains the impact of the cost-benefit of information security in the prescription circulation dilemma. However, it is at a critical state, and there is still a possibility of changing the "no separation of medicine" dilemma.

Table 4. Asymptotic stability of the equilibrium points in true reporting.

Equilibrium point	Eigenvalues	Sign	Stability
$E_1(0,0,0)$	$0, -\pi_l - \omega C_s, -\theta C_s$	$(0,-,-,)$	Unstable
$E_2(1,0,0)$	$C_h + R, \theta C_s, \pi_{hp} - \pi_l - \omega C_s$	$(+,+,\otimes)$	Unstable
$E_3(0,1,0)$	$R, \pi_l + \omega C_s, -2\pi_{hp} - \theta C_s$	$(+,+,-)$	Unstable
$E_4(0,0,1)$	$0, \pi_v - C_h - \theta C_s, L_p - \pi_l - \omega C_s$	$(0,\otimes,\otimes)$	Unstable
$E_5(1,1,0)$	$C_h + R, 2\pi_{hp} + \theta C_s, \pi_l - \pi_{hp} + \omega C_s$	$(+,+,\otimes)$	Unstable
$E_6(1,0,1)$	$-C_h - R, C_h - \pi_v + \theta C_s, L_p + \pi_{hp} - \pi_l - \omega C_s$	$(-,\otimes,\otimes)$	ESS①
$E_7(0,1,1)$	$-R, \pi_l - L_p + \omega C_s, \pi_v - 2\pi_{hp} - C_h - \theta C_s$	$(-,\otimes,\otimes)$	ESS②
$E_8(1,1,1)$	$-C_h - R, C_h + 2\pi_{hp} - \pi_v + \theta C_s, \pi_l - \pi_{hp} - L_p + \omega C_s$	$(-,\otimes,\otimes)$	ESS③

⊗ indicates that the sign is uncertain. If the condition ①②③ is met, it is, respectively, a stable point. Condition ① $C_h - \pi_v + \theta C_s < 0$, $L_p + \pi_{hp} - \pi_l - \omega C_s < 0$; ② $\pi_l - L_p + \omega C_s < 0$, $\pi_v - 2\pi_{hp} - C_h - \theta C_s < 0$; ③ $C_h + 2\pi_{hp} - \pi_v + \theta C_s < 0$, $\pi_l - \pi_{hp} - L_p + \omega C_s < 0$

Situation 2 It is impossible to judge the stability of $E_4(0,0,1)$ evolution based on the positive or negative eigenvalues. However, there are situations in which hospitals do not collaborate, retail pharmacies do not undertake, and the healthcare service platform controls the tripartite dynamic repeated game. Hospitals and retail pharmacies increase the amount of payment for isolated gates and blockchain technology services, respectively, which helps to enhance the willingness of healthcare service platforms to control. However, hospitals and retail pharmacies may reduce the collaboration and take over. Hospitals consider the total expenditure on isolated web gates, prescription circulation information security performance bonds and the value-added revenue generated by the hospital's increased prescription information security capabilities. If the total expenditure is much greater than the value-added revenue, the hospital has a lower probability of collaboration; conversely, the probability of collaboration is higher. At the same time, because of the technology spillover effect of the healthcare service platform, to the extent that the timing of the spillover influences it, the loss of cooperation between hospitals and healthcare service platforms in the short term outweighs the gain. Hospitals tend to implement a non-cooperation strategy to reduce the uncertainty of the combined benefits of prescription outflow in the short term. Similarly, retail pharmacies' incentive to undertake is strongly influenced by the timing of technology provisions such as signature keys and CA accurate name authentication. Therefore, healthcare service platforms should moderately reduce the service fees charged for isolated net gates and blockchain technology on a regulated basis and shorten the technology spillover time through advantageous integration, technology iteration and business innovation to promote a secure, efficient and orderly prescription information circulation process.

Situation 3 If $\theta C_s < \pi_v - C_h$, $L_p + \pi_{hp} - \omega C_s < \pi_l$, hospitals will further promote prescription information collaboration. If $\omega C_s < L_p - \pi_l$, $\pi_v - C_h < \theta C_s + 2\pi_{hp}$, both hospital collaboration and retail pharmacy take-up will be achieved, but the healthcare service platform will no longer be regulated. The evolutionary outcome depends on the respective amounts of the security performance margin for the circulation of prescription information and the net amount of each benefit, with the balance of principal and benefit being the essential condition for hospital collaboration and retail pharmacy take-up.

Situation 4 The ideal outcome is for hospitals to collaborate, retail pharmacies to take over and the healthcare service platform to control, fully utilizing the incentives of the prescription outflow side, the taking over side and the transfer agent. In addition to considering the circulation expenses borne by hospitals, such as security performance deposits for prescription information circulation and isolated gate service fees, it should also ensure that hospitals can compensate for the double loss of prescription circulation by improving their prescription information management capabilities. Therefore, the role of the healthcare service platform in enhancing the prescription information management capability of the hospital under the framework of the information security agreement directly determines whether the hospital adopts a circulation strategy in the tripartite game.

Based on the analysis of the above scenario, a tripartite dynamic evolutionary path can be diagrammed, as shown in Figure 5.

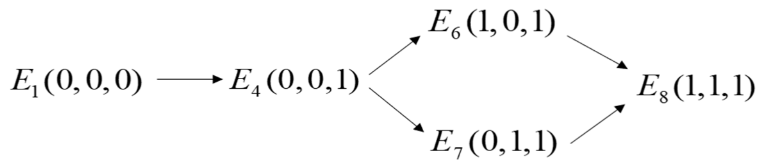

Figure 5. Tripartite dynamic evolutionary path.

Figure 5 shows that the intervention of a third-party organization or the government, represented by a medical service platform, is a prerequisite for linking the outgoing and receiving ends of prescriptions, and existing practices such as the Fuzhou Model and the Yinchuan Model align with the evolutionary path. Hospitals and retail pharmacies decide their implementation strategies based on the information security status of prescription circulation under the control of the healthcare service platform and the various benefits, and the conditions for the secure circulation of prescription information are stringent.

Table 5. Explanation of key variable settings.

Key Variables	Setting basis
1. The performance bond for the information security circulation of prescriptions C_s	*Tianjin Notice on Medical Insurance Policies to Support Prescription Circulation*
2. Profit on sales of prescription drugs π_{hp}	*Guiding Opinions on the Establishment and Improvement of the "Dual Channel" Management Mechanism for National Health Insurance Negotiated Medicines*
3. Hospital isolation gate cost C_h	*Huawei Hospital Network Convergence Solution*
4. Blockchain technology service costs π_l	*Beijing Blockchain Innovation and Development Action Plan* (2020-2022) *Requirements for the Healthcare Sector*
5. Cost of maintaining information on healthcare platforms C_p	*Expert Consensus on the Standardized Management of Prescription Circulation Platforms in Internet Hospitals.*
6. CA Real-Name Authentication Service L_p	*Implementation Opinions on Strengthening Pharmaceutical Management in Medical Institutions and Promoting the Rational Use of Medicines*
7. Loss of social reputation of medical service platforms R	*Supervision and Administration of Network Transactions*
8. Hospital management information system (HIS) upgrading and platform interfacing services π_v	*Notice on the issuance of Hunan Province prescription circulation and supervision of the work programmed (for trial implementation)*
9. Upload collected information on adverse drug reactions S	*Guidelines for the Collection and Reporting of Adverse Drug Reactions in Individual Cases*

5. Simulation analysis

Given that Wuzhou City Health Planning Commission and YiFuZhen cooperated to create China's first prescription-sharing platform, four in-depth studies were conducted at Qingdao YiFuZhen Network Technology Co. Ltd. From March 2021 to February 2023 to obtain the values of the critical variables. The research subjects represent a representative model of third-party platforms to promote prescription circulation. From April to June 2023, the team visited Ali Health (Hainan) Internet Hospital Co. Ltd. to conduct interviews on the reasonableness of the hypothetical model, and the policy study passed expert validation. After the investigation, values are assigned concerning the collated data. The probabilities of implementing circulation, undertaking and control strategies for hospitals, retail pharmacies and healthcare service platforms in the initial state are all 0.5, the number of evolutions is 120, and the basic parameters are $L_h = 85$, $S = 80$, $L_n = 80$, $C_p = 12$, $R = 25$. The key variables are set based on the following Table 5.

5.1. Import of information security payment factor

In order to secure the circulation of prescription information, the study analyses the sharing coefficients of the parties to the game, θ, ω, φ, and the changes in the value of C_s. $\theta \in [0.1, 0.3]$, $\omega \in [0.1, 0.4, 0.7]$, $\varphi \in [0.6, 0.7, 0.8]$. Set array 1: $C_h = 10$, $\pi_{hp} = 120$, $L_p = 90$, $\pi_l = 25$, $\pi_v = 35$,

$C_s = 110$, and the rest of the parameters are set in sequence with the basic parameters.

As seen in Figure 6, hospitals are sensitive to the share of the security performance bond to circulate prescription information. In the initial state, the government led hospitals to promote the outflow of prescriptions. This expenditure weakened the incentive for hospitals to collaborate, and the new attempt to "separate medicine" changed the original profitability of hospitals, resulting in poor prescription circulation. With the regulatory intervention of the medical services platform, the revenue environment for hospitals improved after the circulation of prescriptions, and the incentive for hospitals to collaborate increased. When the security deposit for circulating prescription information is specific, hospitals are less willing to collaborate as their commitment factor increases. The simulation found that the probability of hospital collaboration dropped to 0.78 at $\theta \in (0.1,1]$ and remained stable. The reason for this is that, on the one hand, the security deposit for the circulation of prescription information by hospitals has a deterrent effect on the outflow of prescriptions. In order to resolve the contradiction between the regulation of information security externality and the cost of implementing collaborative strategies of the game subjects, the coefficient of hospital commitment should be reduced as much as possible in practice to control $\theta \in (0,(\pi_v - 2\pi_{hp} - C_h)/C_s)$. It is crucial to ensure that the circulation of patient prescription information is secure and to avoid setting the expenditure too high and discouraging information collaboration at the outflow end. On the other hand, the probability of hospital collaboration increases with the intensity of control of the healthcare service platform. Government-led incentives and third-party externalities will help create a favorable social environment for prescription circulation and further open the prescription outflow channel. Therefore, it is essential to adhere to the overall layout of prescription circulation with government leadership, departmental linkage, hospital collaboration and pharmacy participation; formulate phased, differentiated and subjective control policies around the information security of prescription circulation; and explore a system for identifying the responsibilities of the subjects of prescription circulation under technology empowerment, such as *The Blockchain-based pilot application of electronic prescription circulation value chain* in Chongqing. For example, Chongqing has launched a pilot application of a blockchain-based electronic prescription circulation value chain to promote the interoperability of prescription, sales and regulatory information under the general requirements of information security.

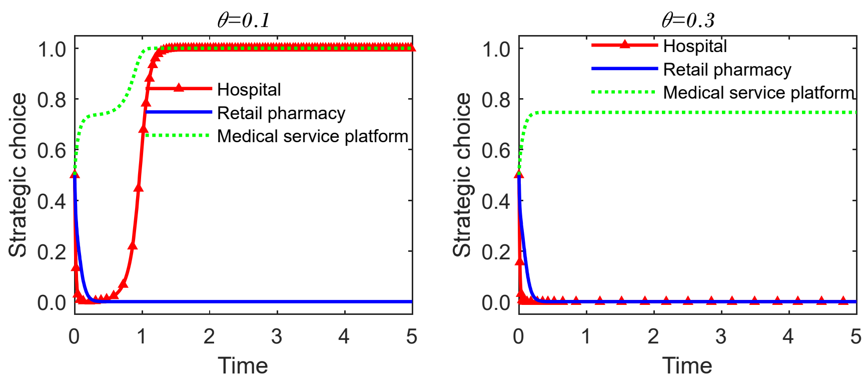

Figure 6. Impact of Hospital Shared Information Security Payment Factor.

Figure 7 shows that the motivation of retail pharmacies to undertake and the probability of control by medical service platforms increase with the increase of the information security performance deposit coefficient for prescription information of retail pharmacies, and the deposit borne by hospitals and medical service platforms is transferred to retail pharmacies. In the case where the total margin borne by the hospital and the medical service platform decreases, there are two possibilities at this point: (1) If the proportion borne by the hospital is more significant than that of the medical service platform, the margin borne by the medical service platform is transferred to the hospital in disguise, and the probability of information security collaboration for the hospital decreases. To ensure information security, the medical service platform will focus on the circulation behavior of the prescription outflow end and increase the control. Although the margin factor borne by retail pharmacies is higher, the control behavior of the medical service platform improves the information security of prescription circulation. It gradually increases the enthusiasm of hospitals to collaborate through the technology spillover effect, and retail pharmacies will gain enormous benefits through prescription circulation in the future. (2) If medical service platforms assume a more significant proportion than hospitals, hospitals will be more willing to collaborate, and the prescription circulation channel will be smooth and stable. Retail pharmacies are influenced by aggressive strategies at the outflow end of prescriptions, and the probability of undertaking increases in the current period as retail pharmacies receive increased profits from prescription drug sales. As a result, the particular phenomenon of retail pharmacies' motivation to take up and increase their margin share, whether based on existing conditions or future expectations, only occurs if the profit from prescription drug sales is greater than the margin expense. However, this state of affairs is unsustainable, and retail pharmacies will refuse to take over if ω is too high or if the deposit for the security of information on the circulation of prescriptions is borne entirely by the retail pharmacy.

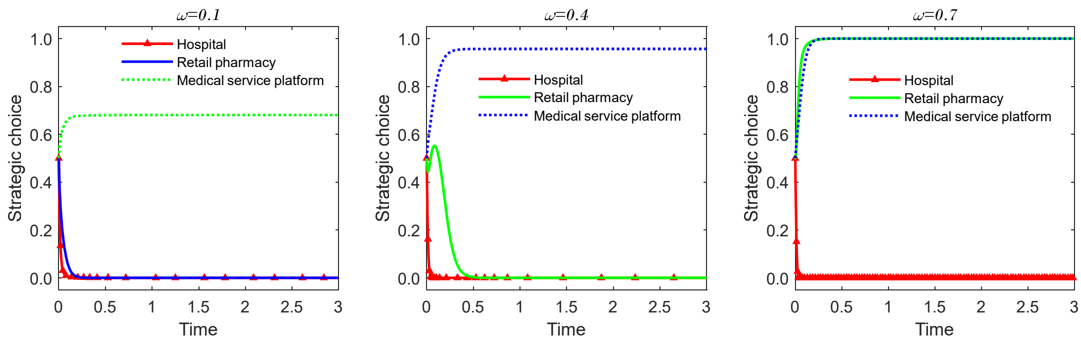

Figure 7. Retail pharmacies share the impact of the information security payment factor.

The higher the healthcare service platform's share of the performance margin for the information security circulation of prescriptions is, the higher the sunk costs when the rational behavior of the healthcare service platform is to increase controls further, push for hospitals and retail pharmacies to participate in prescription circulation information collaboration, and increase revenue from segregated web gates and blockchain technology services. Figure 8 shows that the probability of hospital collaboration rises with the increase in the healthcare service platform's prescription circulation performance margin assumption factor. The reason for this is that, on the one hand, the increase in the proportion of the performance deposit for the information security of prescription information circulation borne by the healthcare service platform will indirectly reduce the expenditure on the information security of prescription circulation in hospitals, which will alleviate hospitals' concerns about the expenditure on prescription outflow and enhance their confidence in prescription outflow. On the other hand, the scale of investment in prescription information security is an essential indicator for judging the qualification of healthcare service platforms. Therefore, increasing the performance margin payment factor for the prescription circulation information security on medical service platforms, increasing investment in software and hardware technology, maintaining the platform system and updating prescription data information promptly will enhance the level of prescription information security, create a safe and stable prescription circulation environment and promote hospital information collaboration.

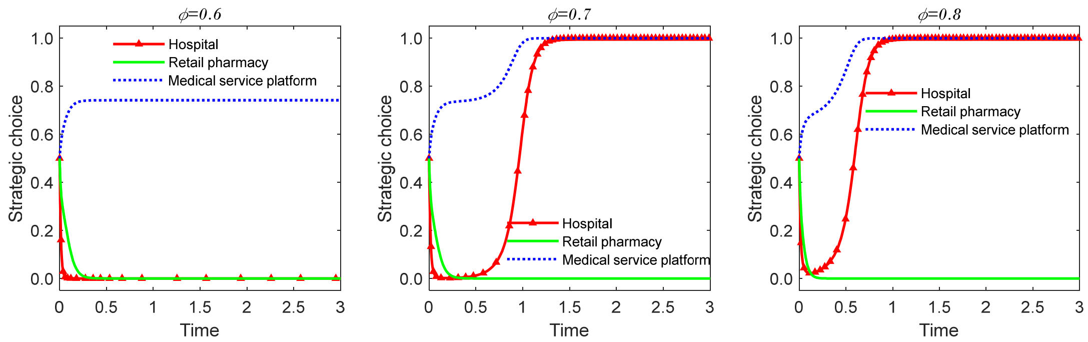

Figure 8. Healthcare service platforms share the impact of information security payment factor.

5.2. Tripartite evolutionary processes with different initial probabilities

Now, we analyze the dynamic evolutionary trajectories and convergence rates of the three parties under different initial probabilities and compare the evolutionary process of the possible states of medical service platform control dominance $[0.2, 0.3, 0.5]$, retail pharmacy undertaking dominance $[0.2, 0.5, 0.3]$ and hospital collaborative dominance $[0.5, 0.2, 0.3]$. $\theta = \omega = 0.3$, $\varphi = 0.4$, $C_s = 110$, and the rest of the values are in the sequential array1.

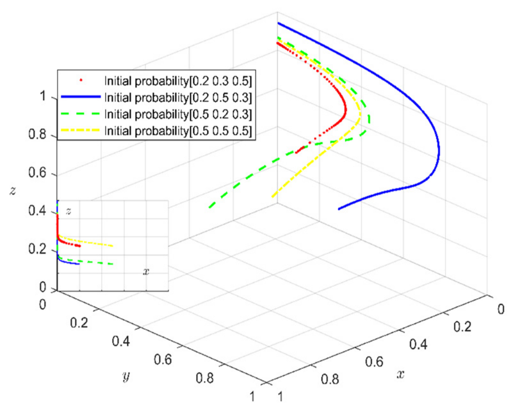

Figure 9. Dynamic evolution process under each initial probability.

The four evolutionary trajectories in Figure 9 all reflect that the control measures of the healthcare service platform are a prerequisite for prescription circulation, with the trajectories of hospital collaboration leadership and retail pharmacy take-up leadership illustrating that without the intervention of the healthcare service platform, the asymptotic equilibrium point is unstable when only hospital collaboration and retail pharmacy take-up are in place. Prescription circulation is not sustainable in this state due to factors such as the loss of existing interests and collaboration loss of all parties. This is not sustainable. Therefore, the medical service platform should strictly comply with the regulations related to the confidentiality of medical data and the laws and regulations related to network information security and take advantage of information technology to give full play to the effectiveness of the control. The three parties should sign an information security and confidentiality agreement to ensure that the information on the circulation of prescriptions is recorded throughout the process to create a safe and stable environment for the circulation of prescriptions and enhance the stability of the information security and coordination of prescriptions.

5.3. Impact of prescription drug sales margin

Consider the impact of changes in the profitability of prescription drug sales π_{hp} on the choice of hospital and retail pharmacy strategies, $\pi_{hp} \in [15,35,55,75]$. Set the array 2: $\theta = 0.3$, $\omega = 0.4$, $\varphi = 0.3$, $C_h = 5$, $C_s = 80$, $L_p = 25$, $\pi_l = 10$, $\pi_v = 121$, and the rest of the values are set in sequence with the basic parameters.

The outflow of prescriptions leads to a reduction in revenue from the sale of prescription drugs in the hospital pharmacy, and the retail pharmacy takes over. From the analysis of the influence of a single entity, as the profit from prescription drug sales increases, the probability of collaboration between the hospital and the retail pharmacy decreases, while the probability of the retail pharmacy taking over increases (Figure 10). From the analysis of the joint influence of the two entities on the outflow side and the taking over side, the larger the value of the profit from prescription drug sales is, the lower the probability of the hospital and the retail pharmacy realizing the collaboration and taking over strategies at the same time. When and only when $\pi_l + \omega C_s - L_p < \pi_{hp} < (\pi_v - C_h - \theta C_s)/2$, the outflow and takeover sides meet the conditions of prescription circulation information security. Therefore, the zero-plus policy transforms hospital-owned pharmacies from profit centers to cost centers, eliminating the conflict-of-interest factor to a certain extent. However, it is still necessary to design a constraint mechanism between hospitals and retail pharmacies, focusing on establishing a hospital-retail pharmacy selection file with prescription information security as the core, publicizing the catalogue of prescription drugs to be included in the scope of circulation and prohibiting directional circulation and selective circulation. To beware the emergence of a conflict of interest, the hospital and retail pharmacies will also be required to disclose the catalogue of prescriptions that are included in the scope of transfer.

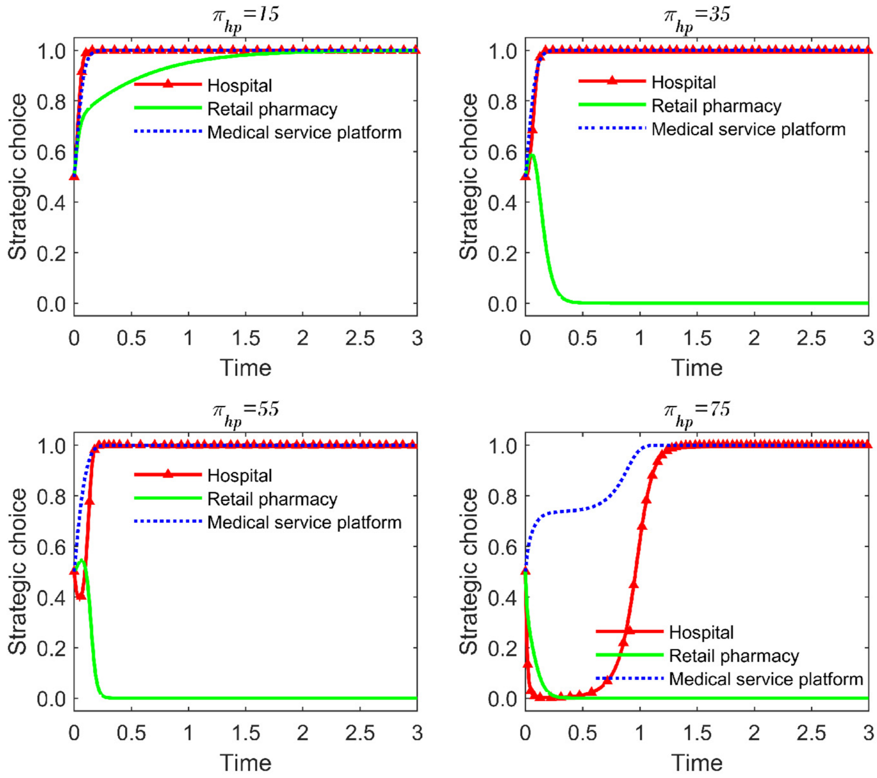

Figure 10. Effect of prescription drug sales profit on stabilization equilibrium point.

5.4. Impact of regulatory behavior of medical service platform

Consider the effects of the change in the values of variables related to hospitals and retail pharmacies by the regulatory behavior of health care service platforms, respectively. Set $(\pi_v, C_h) = \{(95,25),(85,35),(75,45)\}$, $(L_p, \pi_l) = \{(95,25),(75,45),(55,65)\}$, where $\theta = 0.2$, $C_s = 100$, and the rest of the values refer to array 1.

Figure 11 shows that the technology spillover effect of the healthcare delivery platform diminishes, and the probability of hospital collaboration decreases as the hospital's prescription information security management capability increases, and payment for isolated web gate services increases or decreases in the opposite direction. If $\theta C_s < \pi_v - C_h < \theta C_s + 2\pi_{hp}$, the replicated dynamic system is unstable, and hospital collaboration is still being determined. Similarly, Figure 12 reflects that when the security gain of prescription drug sales by retail pharmacies and the cost of blockchain technology services change inversely, the outflow side of the prescription circulation process is missing. Hospitals refrain from participating in the information collaboration, which further reduces the security of the already flowing prescription information, and the incentive for retail pharmacies to take over is then weakened. If $\omega C_s - \pi_{hp} < L_p - \pi_l < \omega C_s$, there needs to be more certainty about take-up by retail pharmacies. The positive and negative impacts of the health service platform controls on the other two parties are less than the security performance margin for the circulation of prescription information or more significant than the sum of the margin and the profit from the sale of prescription drugs, making it robust for hospitals and retail pharmacies to adopt collaboration and take-up strategies, respectively. Therefore, the healthcare service platform should determine $\pi_v - C_h, L_p - \pi_l$, reasonable values as far as possible, shorten the technology spillover time, unconditionally open operational data involving prescription circulation to government authorities, reduce potential prescription information leakage problems at the initial stage of system access, implement dynamic monitoring of information security in the whole process before, during and afterwards, and comprehensively enhance the effectiveness of information security control of the healthcare service platform.

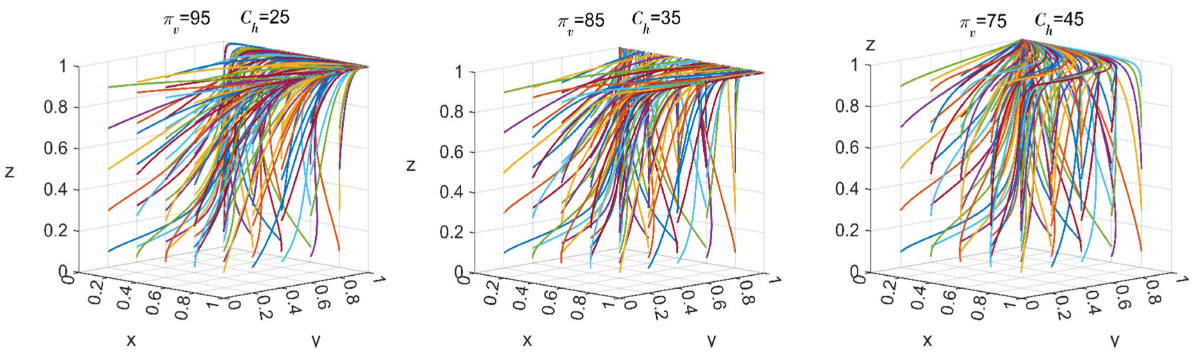

Figure 11. Impact of healthcare service platform regulation on hospital evolutionary strategy.

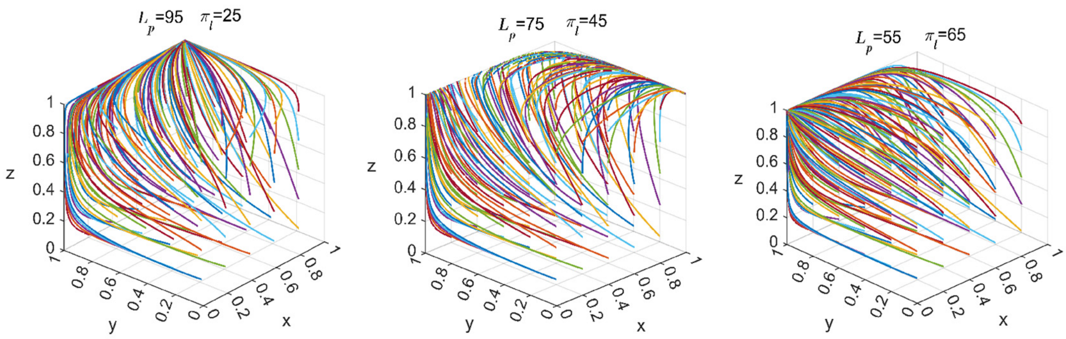

Figure 12. Impact of healthcare service platform regulation on retail pharmacy evolutionary strategy.

6. Discussion

Focusing on the problem of information security circulation of prescriptions, we constructed a tripartite evolutionary game model for hospitals, retail pharmacies and healthcare service platforms to analyze the application conditions and evolutionary paths for different actors to promote the prescription circulation process collaboratively. Numerical simulation analyzes show the impact of changes in critical variables on the evolution of the tripartite strategy, and we put forward the following suggestions.

First of all, the government can link the status of prescription information security maintenance to the amount of the deposit levy, expand interest-related factors horizontally, extend the scope of gradient management vertically, such as Tianjin issued *The Notice on the support of prescription circulation health insurance policy* points out to improve the agreement assessment standards, the results of the assessment of prescription circulation and performance bonds payment link. Give full play to the role of credit mechanisms in prescription circulation, and gradually guide hospitals, retail pharmacies and medical service platforms to achieve self-regulatory behavior in terms of prescription circulation information security with differentiated and personalized management approached in terms of policy formulations.

Second, by formulating information security assessment standards for prescription outflow and a mechanism for compensating for the interchange of resources, establishing a system for monitoring prescription drugs and receiving complaints and reports, and realizing closed-loop regulation of information security in which physicians prescribe, the platform reviews prescriptions, and pharmacists review, the information security of prescription circulation is promoted to achieve collaboration. Hunan Province issued *The Notice of prescription circulation and regulatory work program*, pointing out that the medical institutions involved in prescription circulation are responsible for coordinating the hospital departments, project builders and relevant units to do a good job of information collection, system docking and other work to achieve the HIS and prescription information circulation system of data exchange and sharing.

Further, the medical service platform should regularly report to the relevant authorities on data security status and provide information security training to the flowing entities. The “private key + public key” dual authentication technology is used to avoid security breaches caused by physician or pharmacist errors. A positive interaction mechanism will be established to facilitate circulation with control and promote control with circulation. Regarding Qingdao City’s “Internet + medical insurance” exploration experience, insist that the government take the lead, encourage social forces to provide technical support, and establish a multi-party linkage platform for prescription circulation.

Eventually, external publicity will be strengthened, and the platform will be gradually rolled out to medical institutions and retail pharmacies eligible for access. The government authorities will establish a system of pilot platform acceptance, user rating and evaluation, regulatory authority filing, and dynamic access and withdrawal to create a safe and stable prescription information circulation environment through double audit prescribing and one-party-one-code drug purchase. For example, Fujian Province has established a cell phone service evaluation mechanism for health insurance patients to promote the standardized operation of “dual-channel” electronic prescription circulation. At the same time, the establishment of access and exit mechanisms, platform access organizations, if there are a variety of non-compliance situations, will implement the “one-vote veto”.

7. Conclusions

Security of information plays an essential role in prescription circulation. Achieving collaborative information security for prescription circulation requires the participation of multiple parties. We have constructed a tripartite evolutionary game model. The impacts of the changes of each decision variable on the strategy evolution were analyzed, and the following conclusions were drawn.

(1) When the expenditure on information security performance deposit for prescription circulation information security increases, the probability of hospital collaboration decreases, and the probability of healthcare service platform control increases. In contrast, the probability of retail pharmacy undertaking increases and then decreases. Therefore, under the framework of shared responsibility for

information security, the cost of security guarantees for hospital prescriptions should be appropriately reduced, the information security sharing costs of healthcare service platforms should be increased, and the proportion of prescription information security performance deposits levied on retail pharmacies should be dynamically adjusted in phases.

(2) As the profitability of prescription drug sales increases, the lower the likelihood of hospitals promoting information security collaboration is, the higher the probability of retail pharmacies taking over is, and the weaker the willingness of both parties to achieve collaboration and take over at the same time is. Therefore, the underlying logic of benefit and risk redistribution after prescription outflow should be explored in depth, a corresponding policy basis should be provided, the scope of rights and responsibilities of outflow subjects should be stipulated, the possible sale of prescription outflow information driven by capital should be guarded against, a sound prescription outflow regulatory system and emergency plans for information security incidents should be formulated, and the opinions of hospitals and retail pharmacies on information security maintenance in prescription outflow practice should be widely incorporated.

(3) The regulatory effectiveness of medical service platforms is enhanced when hospitals collaborate, and retail pharmacies undertake them. In contrast, the probability of hospital collaboration and retail pharmacy strategies are positively influenced by the technical spillover effect of medical service platforms. There is a two-way constraint phenomenon between the circulation and control sides. Therefore, the healthcare service platform should clarify the scope of utility of information security of prescription circulation information for hospitals and retail pharmacies, shorten the time of technology spillover, and increase the enthusiasm for information security collaboration between hospitals and retail pharmacies with technology empowerment.

(4) At the early stage of prescription circulation practice, focus on the fundamental role of third-party prescription-sharing institutions represented by medical service platforms or the regulatory intervention of government departments, and build an external environment for information security as a prerequisite for changing hospitals' practice of "feeding doctors with drugs." The government should take the lead and encourage social forces to provide technical support to establish a multi-party platform for prescription circulation. By the requirements of the "two measures," the essential difference between the circulation of prescriptions and the online sale of prescription drugs should be clarified.

We explored the security of prescription information circulation based on asymmetric information and limited rationality and constructed a tripartite game model of a hospital-retail pharmacy-medical service platform. We identified eight pure strategy equilibrium points and one mixed strategy equilibrium point and determined three asymptotically stable points. However, the study did not consider the impact of patients' subjective emotions, such as shame and fear, on the security of prescription information circulation in the case of public health emergencies. Future research will analyze the state and evolution of the four-way game using dynamic repeated game methods.

Use of AI tools declaration

The authors declare they have not used artificial intelligence (AI) tools in the creation of this article.

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Conflict of interest

All authors declare no conflict of interest in this paper.

References

1. L. Liu, L. W. Xie, Risk prevention of online trading of prescription drugs from the perspective of "deregulation and service" (in Chinese), *Chin. Admin. Manag.*, **10** (2021), 33–40. https://doi.org/10.19735/j.issn.1006-0863.2021.10.04
2. B. Liu, C. X. Jiang, Can the reform of the two-vote system promote the innovation of pharmaceutical enterprises (in Chinese), *Nankai Manag. Rev.*, **25** (2022), 54–66.
3. Y. J. Guo, D. Y. Liu, X. R. Tang, M. Hu, Analysis of influencing factors of prescription circulation and qualitative study on platform construction (in Chinese), *China Pharm.,* **34** (2023), 1307–1312. https://doi.org/10.6039/j.issn.1001-0408.2023.11.05
4. H. M. Hussien, S. M. Yasin, N. I. Udzir, M. I. H. Ninggal, S. Salman, Blockchain technology in the healthcare industry: Trends and opportunities, *J. Ind. Inform. Integration*, **22** (2021), 100217. https://doi.org/10.1016/J.JII.2021.100217
5. I. Izonin, N. Shakhovska, Informatics & data-driven medicine, *Math. Biosci. Eng.*, **18** (2021), 6430–6433. https://doi.org/10.3934/mbe.2021319
6. S. A. ElRahman, A. S. Alluhaidan, Blockchain technology and IoT-edge framework for sharing healthcare services, *Soft Comput.*, **21** (2021), 13753–13777. https://doi.org/10.1007/S00500-021-06041-4
7. F. Hassandoust, M. Subasinghage, A. C. Johnston, A neo-institutional perspective on the establishment of information security knowledge sharing practices, *Inf. Manag.*, **59** (2022), 103574. https://doi.org/10.1016/J.IM.2021.103574
8. S. Pal, M. Hitchens, V. Varadharajan, T. Rabehaja, Policy-based access control for constrained healthcare resources in the context of the Internet of Things, *J. Netw. Comput. Appl.*, **139** (2019), 57–74. https://doi.org/10.1016/j.jnca.2019.04.013
9. D. B. Hu, S. L. Huang, Research on decision-making of medical service system considering information platform optimization (in Chinese), *Chin. J. Manag. Sci.*, **11** (2022), 352–360. https://doi.org/10.16381/j.cnki.issn1003-207x.2019.2180
10. Q. T. S. Shen, H. Qian, D. L. Zhang, Attribution model, quantitative assessment and governance path of network medical information risk (in Chinese), *J. Ind. Eng. Eng. Manag.*, **5** (2021), 102–109. https://doi.org/10.13587/j.cnki.jieem.2021.05.009
11. J. Jiang, X. Yu, Y. Lin, Y. Guan, PercolationDF: A percolation-based medical diagnosis framework, *Math. Biosci. Eng.,* **19** (2022), 5832–5849. https://doi.org/10.3934/MBE.2022273
12. P. N. Sindhuja, The impact of information security initiatives on supply chain robustness and performance: an empirical study, *Inf. Comput. Secur.*, **2** (2021), 365–391. https://doi.org/10.1108/ICS-07-2020-0128

13. Y. Wu, L. L. Wang, G. Z. Feng, Research on incentive contract of information security outsourcing of supply chain complementary enterprises under bilateral moral hazard, *Syst. Eng. Theory. Practice*, **42** (2022), 2916–2926. https://doi.org/10.12011/SETP2021-2000
14. R. Gupta, B. Biswas, I. Biswas, S. S. Sana, Firm investment decisions for information security under a fuzzy environment: a game-theoretic approach, *Inf. Comput. Secur.,* **29** (2021), 73–104. https://doi.org/10.1108/ICS-02-2020-0028
15. W. Yang, Y. Yang, H. Chen, How to stimulate Chinese energy companies to comply with emission regulations? Evidence from four-party evolutionary game analysis, *Energy*, **258** (2022), 124867. https://doi.org/10.1016/j.energy.2022.124867
16. J. Q. Gu, S. E. Mei, W. j. Zhong, Information system security investment and coordination mechanism considering interdependence (in Chinese), *Oper. Res. Manag.*, **24** (2015), 136–142.
17. G. Zhu, F. J. Li, G. F. Cao, Z. Y. Jiang, Research on personal health privacy concern and paradox dissolution based on the theory of belief updating (in chinese), *Library Intelligence Work*, **67** (2023), 15–28. https://doi.org/10.13266/j.issn.0252-3116.2023.12.002
18. J. Cai, H. Sun, X. Hu, W. Zhang, How reverse information sharing supports pricing and sales effort decisions: Signaling game-based incentive mechanism design, *Comput. Ind. Eng.*, **177** (2023), 108992. https://doi.org/10.1016/J.CIE.2023.108992
19. Y. Lu, A knowledge-driven decision support system for remote medical management, *Math. Biosci. Eng.*, **20** (2023), 2732–2749. https://doi.org/10.3934/mbe.2023128
20. J. Ji, Q. Pan, W. Zhu, M. He, The influence of own historical information and environmental historical information on the evolution of cooperation, *Appl. Math. Comput.,* **446** (2023), 127902. https://doi.org/10.1016/J.AMC.2023.127902
21. N. Roumeliotis, J. Sniderman, T. Adams-Webber, N. Anand, V. Rochon, C. Parshuram, Effect of electronic prescribing strategies on medication error and harm in hospital: a systematic review and meta-analysis, *J. Gen. Intern. Med.*, **34** (2019), 2210–2223. https://doi.org/10.1007/s11606-019-05236-8