AI-Enabled Smart Healthcare Ecosystem Model and Its Empirical Research

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Abstract. This paper combines the ecosystem theory to study the AI-enabled healthcare ecology and build a smart healthcare ecosystem. The ecosystem growth model is employed to discuss the growth and change patterns of innovative companies adopting AI technology in the smart healthcare ecosystem from a micro perspective. Combining the Lotka-Volterra competition model, this paper delineates that the larger the competition coefficient of AI companies cluster, the more stable their development in the smart healthcare ecosystem will be. The findings are supported by two case studies.

Keywords: Artificial Intelligence (AI) · Smart Healthcare · Business Ecosystem · Ecosystem Growth Model · Lotka-Volterra Competition Model

1 Theoretical Background

Due to the highly specialized nature of the healthcare industry, hospitals have always occupied an absolute core position in the traditional healthcare ecosystem. When hospitals operate at overloaded capacity, the efficiency of the entire ecosystem will decrease, and poor communication among stakeholders will lead to problems such as uneven distribution of healthcare resources. With the development of artificial intelligence (AI) in healthcare, connections in communication and information exchange among stakeholders in the healthcare ecosystem gradually improve, forming a dynamically balanced digital information network. This paper endeavors to build a business model of the future healthcare ecosystem and explore the development patterns of the AI-enabled healthcare ecosystem as well as the competition mechanism of healthcare enterprises based on the new technological revolution.

1.1 Business Ecosystem

The concept of "business ecosystem" has remained popular among researchers and practitioners since James F. Moore proposed it in his article published in Harvard Business

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Review in 1993 for the first time [1]. Inspired by ecology, Moore's concept of business ecosystem provides a metaphor for understanding the intertwined quality of the industries [2]. In this paper, we introduce the business ecosystem into digital economic activities and use ecological analysis to study the dynamic evolutions of different industries [3], offering a new perspective to explain the interactions among stakeholders.

The business ecosystem and the biological ecosystem have various unique features. Similar to its counterpart, the business ecosystem emphasizes the symbiotic and competitive relationship between stakeholders [4, 5]. Viewing business and innovative network management from the perspective of ecosystems, this paper analyzes the key players of the business ecosystem [6], and explains the dynamic evolution of the increasing business and innovation activities in the contemporary world [7–9].

1.2 Ecosystem Growth Model

The growth of new species' populations in the natural world follows a certain pattern. At the primary stage when a new species enters the ecosystem, there is a continuous increase in its number, which will reach the peak at a particular time and then slow down.

The diffusion mechanism of new products in the market is similar to the growth pattern of ecosystems. Reference [10] proposed a product growth model, arguing that the growth model for the timing of the first purchase of a new product was based on the assumption that the probability of purchasing at any given time was linearly related to the number of prior buyers. After the exponential growth of initial purchases reaches a peak in a given period, the exponential decay occurs [11].

1.3 Lotka-Volterra Competition Model

In nature, competitors are everywhere. Populations often do not exist alone, and when competition occurs, the growth of different ecological populations may be inhibited. In ecology, species do not exist alone, but compete with other multiple species to achieve a state of coordinated symbiosis.

We assume that there are only two populations in the ecosystem, and use the Lotka-Volterra equations to describe the growth trends of these two populations under the constraint of competition [12, 13].

The Lotka-Volterra competition equations [14]:

$$\begin{cases} \frac{dN_1}{dt} = r_1 N_1 (1 - \frac{N_1 + \alpha N_2}{k_1}) \\ \frac{dN_2}{dt} = r_2 N_2 (1 - \frac{N_2 + \beta N_1}{k_2}) \end{cases} \tag{1}$$

where N_1 and N_2 denote the number of the two populations, k_1 and k_2 denote the environment capacity of N_1 and N_2. α is the competition coefficient for the effect that species N_1 has on species N_2, β is the competition coefficient of the effect of species N_2 on species N_1. r_1 and r_2 represent the growth rates of populations N_1 and N_2, respectively.

Currently, AI technology has presented new opportunities for business ecosystems, particularly in terms of applications in the field of healthcare [15–17]. Despite the increasing theoretical and practical relevance of AI-enabled business models to healthcare, there has been a lack of research to date that examines AI in healthcare ecosystem from a micro

perspective [18]. Because of the similarities between the nature of the study of organisms in ecology and that of economic and social enterprises, application of ecological models will provide a lesson for the study of healthcare ecosystems. This paper primarily focuses on introducing AI technology into the healthcare ecosystem and constructing a network model of the ecosystem. The ecological growth model is used to uncover the growth patterns of new AI technology in the healthcare ecosystem, and the Lotka-Volterra competition model is employed to reflect the changing trend of the number of clusters of two types of AI companies in a competitive environment.

2 Constructing the Smart Healthcare Ecosystem

2.1 Smart Healthcare Ecosystem

The entrance of AI technology to the healthcare ecosystem has brought about changes in consumer behavior and habit. What with the rapid development of AI medical devices and new ideas about health, people's purchasing behavior has also been changed, and medical device products are no longer limited to hospitals, but are adopted by households as well as professional testing services [19, 20]. Medical device companies have also seized new opportunities for transformation through technological innovation and service improvement. AI image recognition in medical diagnostics can accurately and quickly identify a patient's lesion through deep learning algorithms [21] incubating numerous professional medical imaging and testing agencies who, with their state-of-the-art medical devices, issue professional, accurate and authoritative medical reports for patients in a timely manner.

The implementation of regulations on the multiple-site practice by physicians and the Internet sale of prescription drugs has propelled the rapid development of AI-assisted teleconsultation, which has attracted the Internet giants to the field of healthcare ecology, allowing doctors and patients to enjoy the convenient teleconsultation services with AI-assisted consultation systems. The medical AI can guide the patients to retail pharmacies using the information from the medical consultation. This behavioral change has rejuvenated the traditional healthcare market. Through "AI plus" medical logistics, pharmacies are now able to perfectly match the scale requirements of the increasing needs of pharmaceutical supplies, and pharmaceutical companies can accurately record the corresponding batch number, date of manufacturing and other key information to ensure medication safety (Fig. 1).

2.2 Constructing the Smart Healthcare Ecosystem Model

The fast-growing AI technology has facilitated the formation of an emerging ecosystem of the healthcare industry. Ecologically speaking, the smart healthcare ecosystem shares remarkable similarities with the ecosystem in nature. The stakeholders of the smart healthcare ecosystem include doctors, patients, hospitals, mobile devices, pharmaceuticals, and public healthcare institutions, which form an interdependent and mutually promoting organism that achieves a state of dynamic balance in competition and adds value to the whole system (Fig. 2).

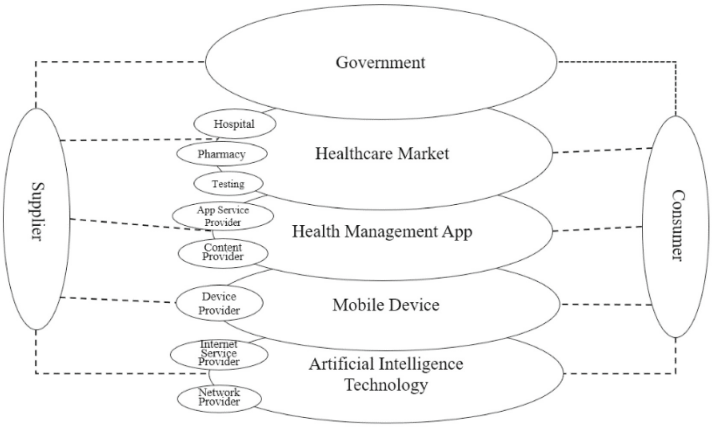

Fig. 1. Smart healthcare ecosystem

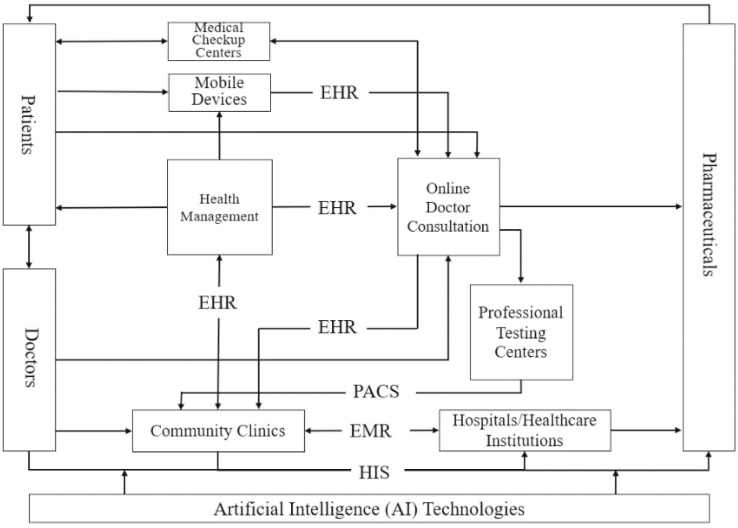

Fig. 2. Model of the smart healthcare ecosystem

2.3 Dynamic Analysis of AI-Enabled Smart Healthcare Ecosystem

The entire smart healthcare ecosystem is supported by AI technology. The activities of stakeholders, such as doctors, patients, health management, professional testing centers, hospitals/healthcare institutions, and pharmaceuticals, close the loop of the smart healthcare ecosystem.

When notified by the health management of illness, the patient can go to the medical checkup center for health screening. The results will be uploaded to the AI online consultation system for online doctor consultation. Depending on the severity of the

condition, the patient can choose to directly buy medicines, do a further specialized examination, or go to a community clinic or hospital for treatment. The professional testing center transmits the AI-assisted diagnostic imaging results to the community clinic, which treats the patient according to his or her condition or, if surgery is required, the patient will be referred to an appropriate hospital or medical institution. As freelancers, doctors can communicate with patients directly, or answer their queries at any time through remote consultation. Some doctors provide medical services in multiple sites, such as community clinics, hospitals and medical institutions.

3 Ecological Growth Model of AI Companies

3.1 Model Specification

The entry of AI technology into the smart healthcare ecosystem has led to a surge in innovative companies adopting AI technology. Based on the ecosystem growth model, we can divide the suppliers in the smart healthcare ecosystem into two categories: one is the companies that first use AI technology for product production and sale, which we call innovators; and the other is called imitators whose adoption of AI technology for product innovation is influenced by environmental and social pressures.

We assume that, at time T, the number of companies that adopt AI for product innovation for the first time is M, and the number of companies that have already done so is N, and the linear relationship between them can be expressed by the equation $M = p + (\frac{q}{k})N$, where p denotes the innovation coefficient, q denotes the imitation coefficient, k stands for the environment capacity. p, q and k are constants, and when $T = 0, N = 0$. The number of innovative companies adopting AI technology in the smart healthcare ecosystem increases with time, and we predict that the number of innovative companies will reach the maximum at a certain time period. Next, we solve the ecological growth model to find time T^* when the number of innovative companies is at its highest, and calculate the maximum number of innovative companies at T^*.

3.2 Ecological Growth Model Solution

The linear function of the number of companies that first adopt AI technology is:

$$M = p + (\frac{q}{k})N \tag{2}$$

$F(T)$ is the probability of all companies in the ecosystem that are likely to adopt AI technology for innovation:

$$F(T) = \int_0^T f(t)dt \tag{3}$$

The number of companies that adopt AI technology for innovation is:

$$N = k * F(T) \tag{4}$$

For companies that have not adopted AI, the probability of their initial use at time T is:

$$\frac{f(T)}{[1-F(T)]} = M(T) = P + \left(\frac{q}{k}\right)N = p + q * F(T) \tag{5}$$

$$\frac{dN}{dt} = k * f(T) = M(T)(k-N) \tag{6}$$

$$\frac{dN}{dt} = \left[p + \left(\frac{q}{k}\right)N\right] * (k-N) \tag{7}$$

$$f(T) = \left[p + q * F(T)\right] * [1-F(T)] \tag{8}$$

solving the above equations, we have:

$$F = \frac{q - p * e^{-(T+C)(p+q)}}{q * [1 + e^{-(T+C)(p+q)}]} \tag{9}$$

Because $F(0) = 0$, we have:

$$C = -\left[\frac{1}{(p+q)}\right] * \ln(\frac{q}{p}) \tag{10}$$

Substituted into the above equation, then

$$F(T) = \frac{1 - e^{-(p+q)T}}{\frac{q}{p}e^{-(p+q)T} + 1} \tag{11}$$

$$N(T) = kF(T) = \frac{k * [1 - e^{-(p+q)T}]}{\frac{q}{p}e^{-(p+q)*T} + 1} \tag{12}$$

Solving the above differential equations, we get:

$$N(T) = \frac{k * (1 - e^{-(p+q)T})}{\frac{q}{p}e^{-(p+q)*T} + 1} \tag{13}$$

When the system reaches the state of equilibrium, the growth of companies using innovative technologies is 0. At this point, let $\frac{dN}{dt} = o$,

$$T^* = \frac{1}{(p+q)}\ln(\frac{q}{p}) \tag{14}$$

$$N\left(T^*\right) = \frac{k(q-p)}{2q} \tag{15}$$

3.3 Model Analysis

After obtaining the innovation coefficient p, imitation coefficient q and environment capacity k of companies that use AI technology in the healthcare ecosystem, we can calculate that the number of companies adopting AI technological innovations in the smart healthcare ecosystem reaches its highest $N(T^*) = \frac{k(q-p)}{2q}$ at time $T^* = \frac{1}{(p+q)}\ln(\frac{q}{p})$. In addition, we also find that only when innovation coefficient p is greater than imitation coefficient q, can the innovative technological changes in the healthcare ecosystem be successfully achieved. Because the understanding of imitators and innovators is closer to the actual meaning represented by the model, the obtained calculation results can accurately reflect the growth trends of innovative companies in the smart healthcare ecosystem.

4 Lotka-Volterra Competition Model

4.1 Model Specification

It's extremely rare to see a single population develops on its own in an ecosystem. Generally, multiple populations coexist in a coordinated manner in a competitive environment. In the smart healthcare ecosystem, there are multiple populations of companies adopting AI technology for innovation, between which business cooperation and competition coexist. For example, in China's smart healthcare market, it is often the Internet conglomerates that adopt innovative technologies, and each of them hold different healthcare ecological resources. Competition among them remains fierce in some healthcare service areas.

Based on the Lotka-Volterra competition model, this paper explores the evolution of two clusters of innovative companies adopting AI technology in the healthcare ecosystem under competitive pressure.

4.2 Model Solution and Analysis

According to the Lotka-Volterra competition model, when the healthcare ecosystem reaches equilibrium, the growth rate of the two types of innovative companies is 0, i.e., when $\frac{dN_1}{dt} = \frac{dN_2}{dt} = 0$, a dynamic equilibrium is reached. Solving the equation, we have:

$$\begin{cases} N_1 = \frac{r_2}{\beta} \\ N_2 = \frac{r_1}{\alpha} \end{cases} \tag{16}$$

where α and β represent the competition coefficients of the two companies respectively, and their values are directly related to the intensity of competition between the two companies. If α is greater than β, then the growth rate of the innovative companies cluster N_1 is greater than that of the innovative companies cluster N_2, and N_1 has a more obvious competitive advantage in the ecosystem, and vice versa when β is greater than α .

4.3 Theoretical Contribution

This paper integrates the ecological growth model and the Lotka-Volterra competition model, and combines the computational derivation process of the ecosystem growth model. The same parameters of the two models are set consistent. The inferences of the fine-tuned Lotka-Volterra competition model are fully consistent with the real situation.

5 Practical Implications of the Smart Healthcare Ecosystem – The Cases of Tencent and Alibaba

The gradual application of AI technology in the field of smart healthcare has resolved the hospital treatment-centered deadlock in the traditional healthcare ecosystem, attracting an overwhelming number of Internet companies to the smart healthcare ecosystem, the most typical being the layout of the three Chinese Internet giants, BAT, the acronym for Baidu, Alibaba and Tencent, in the healthcare business ecosystem. Tencent's Internet healthcare layout has been built around WeChat, leveraging its advantage in the field of communication and socializing to connect doctors and patients and complete the resources layout from doctors to patients. Alibaba's venture into the Internet healthcare industry tends to layout through the existing Tmall platform, targeting primary level community healthcare organizations to attract Internet traffic, and has partly achieved the strategic deployment to close the loop of Internet healthcare ecology. Tencent and Alibaba represent not just individual companies, but the entire ecological chain of companies behind them. We use the two enterprise clusters of Tencent and Alibaba as cases to introduce the practical significance of the smart medical ecosystem model.

Based on the growth model of innovative companies adopting AI technology, we obtain the innovation coefficients, imitation coefficients and environmental capacity of Tencent and Alibaba respectively, which enables us to predict that, the number of companies in the two clusters of Tencent and Alibaba will reach the highest at a certain point in time in the future. This will provide reasonable support for the business and economic layout later on.

For two enterprise clusters in the same smart healthcare ecosystem, Tencent and Alibaba are bound to compete in overlapping businesses. The analysis of the Lotka-Volterra competition model revels that the larger the competition coefficient, the higher the number of enterprise clusters. As an AI company, research and innovation abilities should be the first priority and placed at the core for estimating the competition coefficient. The more advanced the company's technology is, the more evident its advantage in the ecosystem.

6 Conclusion

To study the interactions and changing trends of the stakeholders in the AI-enabled healthcare ecosystem, this paper draws on the business ecosystem as well as the ecosystem model, and builds a smart healthcare ecosystem model. It is found that after introducing AI technology to the healthcare ecosystem, hospitals no longer occupy the core

position, and the said system will become more like an interconnected ecological network. After decentralization, the stakeholders in the healthcare ecosystem also undergo some new changes, most notably the gradual increase in the number of AI technology companies. In a competitive environment, companies with a greater competition coefficient will be more likely to gain a survival advantage. Thus, it is of vital importance to keep promoting technological innovations in the field of healthcare technologies so that companies can be invincible in the business ecosystem.

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