Evolutionary Game Analysis of Smart Elderly Care System

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Abstract: In recent years, China's elderly population continues to grow. Population aging is becoming more and more serious, and the corresponding pension configuration problem has not been improved. This situation has left the country with a huge demand for elderly services. The traditional model of elderly care services has been difficult to meet the current situation in China, so it is urgent to explore the smart elderly care service problem. Therefore, this paper starts from the evolutionary game theory, takes the pension institutions and the elderly as the game players, and constructs a two-party evolutionary game model. The system dynamics theory is provided to analyze the stability of the model and derive the optimal strategy selection of players. The results of this study show that regardless of the participation or non-participation of the elderly, care institutions will choose a positive improvement strategy to enhance the quality of elderly care services. This study provides a certain theoretical basis for the intelligent development and improvement of China's pension problems.

Keywords: Evolutionary Game; Smart Elderly Care; Recommendations; Stability Analysis; Payoff Matrix

1. Introduction

Population aging is one of the important issues facing today's social development. China's elderly population over the age of 60 will exceed 300 million. Therefore, China should vigorously develop the pension industry [1]. With the increasing aging of China's population and the booming of the digital economy, there are a number of dilemmas associated with smart elderly care [2]. Therefore, how to effectively solve the problem of smart elderly care is very necessary [3] and of great practical significance.

At present, scholars have paid attention to smart elderly care service. Wan et al. [4] compared the domestic situation with that of foreign countries, and found that domestic and foreign research on the smart elderly care platform is still in the exploratory stage, but the domestic enthusiasm for the development and research of the smart elderly care platform is significantly higher than that of foreign countries. Liao [5] constructed a global collaborative smart elderly service model and explores solutions and realization path of smart elderly service problems. Wang et al. [6] used case study method to conduct field research, and used the three-dimensional analysis framework of "supply targets-supply subjects-supply tools" to explore the systematic construction of the supply mechanism of community-based intelligent elderly care services. Sun et al. [7] analyzed the influential mechanism of digital platform to drive the optimization of the supply structure of smart elderly care services, and explored the optimal stabilization strategy of the supplying body. Wen and Liu [8] explored the uncertainty factors influencing smart elderly care, put forward coping strategies on the basis of the integrated analysis of "technology-subject-situation". Smart elderly care can not be separated from the relevant government policies [9]. Zhu and Deng [10] supported that to cope with a series of legal and ethical dilemmas arising from smart elderly care, it is essential to build a perfect legal system, improve the people's ethical literacy, and promote the participation of all society.

Li et al. [11] drew on the smart elderly care service models of four countries, namely the United States, France, Canada and Sweden, and conducted a questionnaire survey on community smart elderly care services in Hefei. They used a binomial logistic model to analyze the receptivity and influential factors of smart elderly care service models in foreign countries. Feng [12] used logistic regression model to regress residents' integration and the demand of smart elderly care, and community home-based elderly care service. On the basis of these studies, she found that age, education status, and number of children affect the selection of elderly care service models. Yue [13] constructed the home-based elderly care relying on smart communities through "Internet +". Taking the new model of smart elderly care in Xiamen as an example can not only solve traditional families' elderly care but also drive the development of smart home-based elderly care products and services. Wang and Tong [14] used government platforms as media, communities as carries, and needs of the elderly as guidance, and utilized information technology to provide customized elderly care service facilities for different communities. The traditional model is no longer able to meet the development of society. In the context of the "Internet +" era, Ye and Feng [15] found that building a diversified platform through intelligent machines and digital technology, and establishing a standardized system for community elderly care and a management system for elderly care data can improve quality and efficiency. Chen et al. [16] found that the smart community care service model integrating big data, IoT, and AI technologies can meet the needs of the elderly groups for medical care, daily care, and emotional comfort, which provides a new idea for China's pension industry. On the basis of humanistic care, Jia and Wang [17] oriented to the needs of the elderly to realize the convenience and precision of home-based elderly care services. To solve the current problems of smart elderly care, Zhang and Yan [18] proposed that what needs to be done is: to set up a national big data center for the smart pension industry, to promote the balance between the supply of community-based smart elderly care services and the needs of the elderly, and to enhance the ability of the elderly to purchase smart products. Relying on Internet big data to establish a credit system related to smart aging. In summary, promoting smart elderly care service and improving the supply level of elderly services are conducive to alleviating resource shortages of elderly services in China [19].

The above scholars have conducted relevant research on smart elderly care, which provides references and guidance for further exploration. This study adopts evolutionary game theory to explore smart elderly care problems, and analyzes the system stability on the basis of relevant system dynamics theories. This study aims to provide theoretical guidance for smart elderly care problems.

The remaining part of the paper is structured as follows. Section 2, this paper constructs a two-party evolutionary game model and describes the basic assumptions and notions of models. Section 3 analyzes the stability of the game model. Section 4 follows with a summary and provides some policy recommendations.

2. Model Building

The existing model of elderly care cannot meet the demand, and the elderly care institutions can update services to attract the elderly. Therefore, we choose care institutions and the elderly as players. In terms of care institutions, if the institutions want to attract the elderly to participate, they need to continuously improve their "hard power" and "soft power". Hard power can be understood as the renovation of facilities and the increase of sports equipment. Soft power requires care organizations to integrate science and technology such as IoT, big data, cloud computing, artificial intelligence, geo-location, AI, etc. into the platform. However, the renovation of facilities and upgrading of technology require elderly care organizations to pay huge costs, and it remains to be considered whether the elderly will accept the new technology. Therefore, the strategy choices for elderly care organizations are (positive improvement, and negative improvement). As for the change of the elderly care organizations, if the elderly can accept new things and have a certain economic level, then the elderly will move into the elderly care organizations. But there are some old people who stick to the old rules, do not know much about the new technology and technology, and are affected by the economic level. These people will not be interested in participating in the elderly care institutions. Therefore, the strategy choices of the elderly are (positive participation, and negative participation). The above two game subjects have limited rationality and the ability of continuous learning. The elderly and care institutions tend to choose the strategy that can maximize the benefits in the continuous learning. Therefore, strategies of smart elderly care system are (positive improvement, and positive participation), (positive improvement, and negative participation), (negative improvement, and positive participation) and (negative improvement, and negative participation).

Parameters in the evolutionary game model of the smart elderly care system are set as follows, and the main parameters are set as shown in Table 1.

Table 1. Notations and Definitions

Notation	Definition
C_1	The cost incurred by care institutions in making positive or negative improvements
C_{11}	The additional costs when care institutions choose a positive improvement strategy and the elderly choose a positive participation strategy
B_{11}	Benefits of the elderly choosing a positive participation strategy
B_{12}	Benefits of the elderly choosing a negative participation strategy
C_{12}	The additional cost paid by care institutions when the elderly choose a negative participation strategy
F_{11}	The expenses paid by the elderly due to positive participation
D_{11}	The service experience the elderly receive when care institutions adopt positive improvement strategies
D_{12}	The service experience the elderly receive when care institutions adopt negative improvement strategies
D_{21}	The service experience received by the elderly
F_{21}	The expenditure costs received by the elderly

To construct the evolutionary game model, this paper makes the following assumptions:

(1) In the game process of smart elderly care system, we assume that, for care institutions, the probabilities of choosing positive and negative improvement strategies are, respectively, x and $1-x$; for the elderly, the probabilities of choosing positive and negative participation strategies are, respectively, y and $1-y$, where $x, y \in [0,1]$.

(2) C_1 denotes the cost incurred by care institutions in making positive or negative improvements (e.g. accommodations, equipment, labors). We define C_{11} as the additional costs (e.g. daily care, medical monitoring, telemedicine, and other smart senior care services) when care institutions choose a positive improvement strategy and the elderly choose a positive participation strategy. B_{11} refers to the benefits that the elderly choose a positive participation strategy. B_{12} and C_{12} denote the benefit and additional cost paid by care institutions when the elderly choose a negative participation strategy, respectively.

(3) F_{11} denotes the expenses paid by the elderly due to positive participation. D_{11} and D_{12}, respectively, refer to the service experience the elderly receive when care institutions adopt positive and negative improvement strategies. D_{21} and F_{21} denote the service experience and expenditure costs received by the elderly when they choose to participate negatively and care institutions choose to improve positively, respectively.

The game payoff matrix obtained on the basis of the above assumptions of care institutions and the elderly is shown in Table 2.

Table 2. The Payoff Matrix of Care Institutions and the Elderly

		The elderly	
		Positive partici-pation	Negative partici-pation
Care institu-tions	Positive improve-ment	$(B_{11} - C_1 - C_{11}, D_{11} - F_{11},)$	$(B_{12} - C_1 - C_{12}, D_{21} - F_{21})$
	Negative improve-ment	$(B_{11} - C_1, D_{12} - F_{11})$	$(B_{12} - C_1, 0)$

3. Model Analysis

To analyze the game payoff matrix, let the expected payoff of care institutions choosing positive improvement be U_{11}, the expected payoff of care institutions choosing negative improvement be U_{12}, and the average payoff be $\overline{U_1}$, then U_{11} and U_{12}, respectively, are

$$U_{11} = y\left(B_{11} - C_1 - C_{11}\right) + \left(1-y\right)\left(B_{12} - C_1 - C_{12}\right) \quad (1)$$

$$U_{12} = y\left(B_{11} - C_1\right) + \left(1-y\right)\left(B_{12} - C_1\right) \quad (2)$$

$$\begin{aligned}\overline{U_1} &= xU_{11} + \left(1-x\right)U_{12} \\ &= x[y\left(B_{11} - C_1 - C_{11}\right) \\ &\quad + \left(1-y\right)\left(B_{12} - C_1 - C_{12}\right)] \\ &\quad + \left(1-x\right)[y\left(B_{11} - C_1\right) \\ &\quad + \left(1-y\right)\left(B_{12} - C_1\right)]\end{aligned} \quad (3)$$

The replicated dynamics equation of care institutions is

$$\begin{aligned}F\left(x\right) &= x(U_{11} - \overline{U_1}) \\ &= x(1-x)(U_{11} - U_{12}) \\ &= x(1-x)[C_{12} + y(C_{11} - C_{12})]\end{aligned} \quad (4)$$

Similarly, the replicated dynamics equation of the elderly is

$$\begin{aligned}F\left(y\right) &= y\left(1-y\right)\left(U_{21} - U_{22}\right) \\ &= y\left(1-y\right)[x(D_{11} - D_{12} \\ &\quad - D_{21} + F_{21}) + D_{12} - F_{11}]\end{aligned} \quad (5)$$

The replicated dynamic system of care institutions and the elderly constituted by equations (4) and (5) is

$$\begin{cases} \dfrac{dx}{dt} = x(1-x)[C_{12} + y(C_{11} - C_{12})] \\ \dfrac{dy}{dt} = y\left(1-y\right)[x(D_{11} - D_{12} - D_{21}) \\ \quad + F_{21}) + D_{12} - F_{11}] \end{cases} \quad (6)$$

Let $\frac{dx}{dt} = \frac{dy}{dt} = 0$, five evolutionary game equilibrium points obtained are $G_1(0,0)$, $G_2(0,1)$, $G_3(1,0)$, $G_4(1,1)$, and $G_5(x^*, y^*)$, where

$x^* = \frac{C_{12}}{C_{12} - C_{11}}$, $y^* = \frac{F_{11} - D_{12}}{D_{11} - D_{12} - D_{21} + F_{21}}$.

According to reality, only the first four points are analyzed. The stability of the equilibrium points are analyzed using the Jacobian matrix. The Jacobian matrix obtained by taking the partial derivatives of $F\left(x\right)$ and $F\left(y\right)$ is

$$J = \begin{bmatrix} \dfrac{\partial F\left(x\right)}{\partial x} & \dfrac{\partial F\left(x\right)}{\partial y} \\ \dfrac{\partial F\left(y\right)}{\partial x} & \dfrac{\partial F\left(y\right)}{\partial y} \end{bmatrix} \quad (7)$$

Where

$$\begin{cases} \dfrac{\partial F\left(x\right)}{\partial x} = (1-2x)[C_{12} + y(C_{11} - C_{12})] \\ \dfrac{\partial F\left(x\right)}{\partial y} = x(1-x)(C_{11} - C_{12}) \\ \dfrac{\partial F\left(y\right)}{\partial x} = y(1-y)(D_{11} - D_{12} \\ \quad - D_{21} + F_{21}) \\ \dfrac{\partial F\left(y\right)}{\partial y} = (1-2y)[x(D_{11} - D_{12} \\ \quad - D_{21} + F_{21}) + D_{12} - F_{11}] \end{cases} \quad (8)$$

On the basis of equations (7) and (8), the determinant and trace of the matrix J, respectively, are

$$\begin{aligned}\det J &= (1-2x)[C_{12} + y(C_{11} - C_{12})] \cdot \\ &\quad (1-2y)[x(D_{11} - D_{12} - D_{21} \\ &\quad + F_{21}) + D_{12} - F_{11}] - x(1-x) \cdot \\ &\quad (C_{11} - C_{12})\, y(1-y) \cdot \\ &\quad \left(D_{11} - D_{12} - D_{21} + F_{21}\right)\end{aligned} \quad (9)$$

$$\begin{aligned}trJ &= (1-2x)[C_{12} + y(C_{11} - C_{12})] \\ &\quad + (1-2y)[x(D_{11} - D_{12} - D_{21} \\ &\quad + F_{21}) + D_{12} - F_{11}]\end{aligned} \quad (10)$$

Equilibrium points G1(0,0), G2(0,1), G3(1,0), and G4(1,1) are brought into the Jacobian matrix to obtain the determinant and trace of the matrix J. Specific results are shown in Table 3.

According to the system dynamics, the system is in a stable state when $detJ > 0$ and $trJ < 0$ are satisfied. We can make the following conclusions by analyzing points $G_1(0,0)$, $G_2(0,1)$, $G_3(1,0)$, and $G_4(1,1)$.

(1) When $D_{11} - D_{21} + F_{21} - F_{11} < 0$ and $D_{12} > F_{11}$ are satisfied, $G_3(1,0)$ is an ESS. The smart elderly care system is in a stable

state. The stable strategy of the model is (positive improvement, and negative participation).

(2) When $D_{11}-D_{21}+F_{21}-F_{11}>0$ and $D_{12}>F_{11}$ are satisfied, $G_4(1,1)$ is an ESS. The smart elderly care system is in a stable state. The stable strategy of the model is (positive improvement, and positive participation).

(3) When $D_{11}-D_{21}+F_{21}-F_{11}<0$ and $D_{12}<F_{11}$ are satisfied, $G_3(1,0)$ is an ESS. The smart elderly care system is in a stable state. The stable strategy of the model is (positive improvement, and negative participation).

(4) When $D_{11}-D_{21}+F_{21}-F_{11}>0$ and $D_{12}<F_{11}$ are satisfied, $G_4(1,1)$ is an ESS. The smart elderly care system is in a stable state. The stable strategy of the model is (positive improvement, and positive participation).

The above findings suggest that over time, whether the elderly adopt positive or negative participation strategies, care institutions do gradually tend to choose a positive improvement strategy. To improve the quality of elderly care services, care institutions should upgrade their strengths, which include hard strengths (e.g. facilities) and soft strengths (e.g. intelligence and digitalization).

Table 3. The Determinants and Traces of Matrix J

Equilibrium points	detJ	trJ
$G_1(0, 0)$	$C_{12}(D_{12}-F_{11})$	$C_{12}+(D_{12}-F_{11})$
$G_2(0, 1)$	$-C_{11}(D_{12}-F_{11})$	$C_{11}-(D_{12}-F_{11})$
$G_3(1, 0)$	$-C_{12}(D_{11}-D_{21}+F_{21}-F_{11})$	$-C_{12}+(D_{11}-D_{21}+F_{21}-F_{11})$
$G_4(1, 1)$	$C_{11}(D_{11}-D_{21}+F_{21}-F_{11})$	$-C_{11}-(D_{11}-D_{21}+F_{21}-F_{11})$

4. Conclusions and Recommendations

The ageing of China's population is becoming more and more serious, so it is imperative to solve elderly care service problems. The traditional model of old-age care can no longer meet the needs of the country. Therefore, we need to adopt smart elderly care. According to the evolutionary game theory, this paper constructs a two-party evolutionary game model of elderly care institutions and the elderly, and analyzes the model stability. This study finds that care institutions should adopt a positive improvement strategy to improve the quality of elderly care. Introducing some smart services such as daily care, medical monitoring, and telemedicine can provide the elderly a better experience. Meanwhile, the government should adopt appropriate policies to supervise care institutions and establish laws and regulations to regulate smart elderly care.

Based on the above conclusions, policy recommendations are given as follows.

(1) For the elderly

Faced with illegal fund-raising and frauds such as providing "elderly care services" and "elderly care assistance", the elderly should raise their awareness of recognizing and preventing fraud. Entering the age of information technology, the elderly should actively participate in intelligent elderly care, for example, learning to use the emergency telephone dialing and mobile hospital appointments and so on. Enjoy the convenience brought by the digital technology intelligent service through the smart elderly service, and enhance the sense of happiness and security in life.

(2) For care institutions

First, care institutions can realize the registration of the check-in and check-out of the elderly through information technology and improve management efficiency. Through the information management system to record the condition of the elderly, daily life and share with their families in real time, the digital management can protect the health of the elderly and supervise the work of medical staff. Second, by utilizing big data technology, care institutions can assess the physical condition of the elderly and calculate the probability of danger to effectively prevent the occurrence of danger. Third, developing and manufacturing multifunctional, high-quality, intelligent robots with companion, service, and care functions is conductive to saving human resources and improving the quality of services.

(3) For governments

Governments should continue to improve industrial policies and actively carry out pilot projects on smart elderly care. Improve the quality of public cultural services and provide more cultural products and services suitable for the elderly. Encourage regions to build data platforms for smart elderly care and improve the efficiency of data utilization. Strengthen the supervision of elderly care organizations to avoid elder abuse. Furthermore, strengthening human resources and constructing an elderly service network comprising the government, the community and elderly care institutions can provide comprehensive elderly care services.

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