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Evolutionary game analysis of building a sustainable intelligent elderly care service platform

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With the rapid aging of populations and advancements in information technology, the development of intelligent elder-care service platforms (IESPs) has gained momentum. This paper examines the feasibility and strategies for constructing an IESP. Unlike commercial internet platforms, IESP facilitates transactions in elderly care services, which are quasi-public goods requiring government guidance and multi-stakeholder collaboration. Utilizing value co-creation theory, this study constructs a tripartite evolutionary game model involving a digital technology company, a social organization, and an elderly care service provider to analyze factors influencing stakeholder behavior. The findings reveal that sustained value co-creation is influenced by platform revenue, participation costs, reputation effects, and government subsidies. To optimize outcomes, the government should balance stakeholder interests, ensure reasonable profits for the digital company and social organization, and reduce participation costs through grassroots mobilization, data support, and subsidies for digital transformation. Strengthening reputation management and standardizing service evaluations are also crucial for achieving system equilibrium.

Keywords Intelligent elderly care service platform, Evolutionary game, Value co-creation, Quasi-public goods, Multiplayer

According to the United Nations criteria, as of 2023, nearly half of the countries worldwide qualify as aging countries, with more than 7% of their population aged 65 and above. Specifically, over 20 countries have reached super-aged status, where this demographic constitutes more than 20% of the population[1]. The UN's World Social Report titled "Leaving No One Behind in An Ageing World" underscores that the global trend of aging primarily stems from increased life expectancy and reduced family size. These factors have consequently led to a rapid escalation in demand for elderly care services[2]. With the continuous innovation and application of cutting-edge technologies such as the Internet of Things (IoT), artificial intelligence (AI), and big data, traditional elderly care service patterns are increasingly inadequate in meeting diverse service needs[3,4]. Digital technology is propelling the migration of government services to the cloud[5,6]. The digital transformation of government departments provides policy support and environmental safeguards for the development of intelligent elder-care service platform (IESP). The outbreak of the COVID-19 pandemic has prompted community workers to help elderly individuals bridge the digital divide, leading some seniors to begin using online platforms to meet their daily needs[7]. These developments have accelerated the informatization and intelligentization of the elderly care industry.

IESP plays a pivotal role in optimizing and integrating resources, as well as enhancing the welfare of the elderly[8–10]. However, the construction of IESP still faces multiple challenges. Firstly, the elderly care industry exhibits characteristics of quasi-public goods, where relying solely on market forces may result in unequal resource distribution, making it challenging to ensure fairness and inclusiveness in service provision. Secondly, the elderly population faces limitations in terms of technological acceptance, information access, health status and privacy concerns[11–14]. These factors pose significant difficulties in the promotion of IESP, requiring substantial financial investment with long investment return periods. The private capital often lacks interest and patience for such projects. Therefore, establishing a sustainable IESP necessitates government leadership, policy support, and financial investment to guide the participation of various stakeholders.

This paper takes the "Pulaohui"[15] elderly care service platform, launched by the Civil Affairs Bureau of Pudong New Area in Shanghai, as an example. The platform integrates government, social, and market resources

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to provide diversified and specialized services for the elderly. Unlike commercial internet service platforms, the construction and operation of "Pulaohui" do not rely on a single internet technology company but require collaboration and coordination among multiple entities. The government commissions the development of the platform through a tender process to a digital technology company[16]. Once completed and approved, the platform is handed over to a social organization for operation, selectively incorporating elderly care service providers to facilitate market-oriented operations[17]. Consequently, the digital technology company, social organization, and elderly care provider each play crucial roles in the platform's construction and operation.

A pertinent question arises regarding how the government can guide these entities to collaborate and sustain the long-term operation of IESP. To address this, we employ the theory of value co-creation and evolutionary game methodology to construct a tripartite evolutionary game model involving the digital technology company, social organization, and elderly care provider. The model explores the impact of policy factors on the behavioral strategies of each stakeholder and examines measures to promote active participation in value co-creation, aiming to build a sustainable IESP.

The primary contribution of this paper lies in its innovative consideration of the construction and operation of platforms providing user-paid quasi-public goods. This approach transcends previous studies that focused solely on commercial platforms developed and operated by single companies, thus expanding the research perspective on platform ecosystems. Currently, the development of IESP in various countries is still in its infancy. This study can partially reveal the intrinsic mechanisms underlying the behavioral evolution of various stakeholders. Consequently, it offers theoretical support and policy recommendations for the future advancement of smart elderly care services, as well as the government's endeavors in promoting the construction of digital government platforms.

The remainder of this study is organized as follows. Section 2 reviews the related literature. Section 3 describes the model. Section 4 derives equilibrium strategies of each party and analyses the stability of these strategies. In Section 5, the theoretical results are validated through numerical simulation. Finally, we summarize the paper in Section 6 and relegate all the proofs to the Appendix.

Literature review

Value co-creation theory

This study is related to the research stream utilizing the theory of value co-creation to analyze the platform ecosystems. The value co-creation theory is progressively evolving as a novel paradigm within the field of management studies[18]. As this concept is increasingly adopted across various domains, its theoretical origins have become nebulous and challenging to trace[19]. Since Prahalad and Ramaswamy[20,21] emphasized that value is no longer created unilaterally by firms but is co-created through interactions between firms and customers, the concept of value co-creation has garnered significant attention from both academics and practitioners. The service-dominant logic (S-D Logic) propounded by Vargo and Lusch[22,23] has emerged as the primary explanatory framework for this theory, emphasizing that value is collectively generated by all participants involved in the process of service provision and exchange[24].

Initially, value co-creation focused solely on the dyadic relationship between enterprises and consumers, but it has gradually broadened its scope to encompass an ecosystem characterized by collaborative interactions among multiple actors within a network[25]. In contrast to the conventional organizational context, which underscores consumer engagement and direct interactions between supply and demand sides for value co-creation, the platform ecosystem accentuates the symbiotic interdependence, complementary innovation, and resource integration among platform and enterprises, exploring avenues for value co-creation involving diverse actors[26,27]. In essence, the platform ecosystem underscores the collaborative engagement of both the platform sponsor and all autonomous complementors in the co-creation of value[28,29].

Currently, there have been studies that integrate the theory of value co-creation with evolutionary game methodology. Mei, et al.[30] investigated the mechanisms for coordinating the participation of manufacturers, retailers, and consumers in value co-creation within the service supply chain system. Dou, et al.[31] delved into the evolutionary process of value co-creation behaviors between heterogeneous subsidiaries within a group and consumers. Dou, et al.[32] investigated the value co-creation behaviors between a shared supply chain platform and manufacturers. However, similar to the majority of studies, they treated the platform as a monolithic entity, without considering the development and operational issues behind the platform.

Platform operation and management

Our research is concerned with the operation and management of digital platforms, with current studies predominantly focused on large commercial platforms. Garud, et al.[33] used Uber Technologies as a case study to examine how sharing economy platforms navigate market and regulatory challenges when entering new markets. Zeng, et al.[34] conducted an in-depth longitudinal case study of Tencent to reveal how platform-based entrepreneurial firms achieve scale growth within a platform ecosystem. Mai, et al.[35] developed an evolutionary game theory model concerning user behavior and provider responses to investigate how commercial service platforms can enhance their performance by managing user behavior. In addition to research on established commercial platforms, Murthy and Madhok[36] directed attention towards overcoming challenges during the initial stages of platform development. They found that the scope of platform sponsors' engagement, which includes both complementors and consumers, is crucial to their participation in value co-creation.

In the realm of platform governance, Gawer[37] proposed an integrative framework for platform management research, bridging the perspectives of economic bilateral markets and engineering design. Huber, et al.[38] presented a process theory that delineates the dynamic governance practices within platform ecosystems, revealing how to navigate the tension between cocreated value and governance costs. Saadatmand, et al.[39] examined the interaction between governance mechanisms and technological architecture within digital platforms. They identified three organizational forms—vertical, horizontal, and modular—and investigated the impact of these forms on complementors. Kretschmer, et al.[40] argued that platform ecosystems require the coordination of multiple stakeholders, among whom conflicts of interest may arise. They conceptualized the platform as a meta-organization, with a focus on the sources of power within the ecosystem, the incentives used to attract participants, and the governance mechanisms for coordination.

Government-led digital service platforms

Our research is closely aligned with government-led digital service platforms. At present, a considerable portion of related research is centered on e-government[41]. Morgeson and Mithas[42] compared the performance of U.S. federal government websites with that of private e-commerce sites, finding that e-government websites were of lower quality and exhibited significant disparities among federal agencies. Venkatesh, et al.[43] investigated citizens' preference structures for using e-government services, thereby providing insights for the design of these services. MacLean and Titah[44] summarized empirical studies on the impact of e-government, using public value theory to categorize the roles that generate value and the nature of the impacts. Hammerschmid, et al.[45] examined the prevailing governance paradigms in the context of public sector digitalization, arguing that digital reforms are driven by top-down initiatives, with collaboration between public sector actors and organizations being central to these reforms.

In the field of eldercare services, many scholars have approached the issue from the demand side, employing empirical research methods to explore the factors influencing elderly individuals' use of digital platforms[46–48]. Frishammar et al.[49,50] utilize qualitative and quantitative analyses to investigate strategies for enhancing the adoption of digital platforms among elderly users. In contrast to these demand-side perspectives, this study adopts a supply-side approach, focusing on the evolutionary game dynamics among stakeholders of eldercare service platforms. Several researchers have also employed evolutionary game models to address operational challenges in these platforms. Wang, et al.[51] analyzed the regulatory challenges of community eldercare services within the context of the "Internet Plus" initiative by constructing a four-party evolutionary game model involving the government, service providers, platforms, and the elderly. Shi, et al.[52] employed a tripartite evolutionary game model, encompassing the government, smart eldercare service providers, and the elderly, to simulate strategic decision-making within the multi-agent governance system of smart eldercare services in China. Mao, et al.[53] developed a four-party evolutionary game model involving local governments, communities, service enterprises, and elderly households, using system dynamics to simulate the transformation pathways of smart eldercare services. Unlike these studies, this research distinguishes between platform development and operational stakeholders, moving away from a monolithic view of the platform. This innovative approach allows for a more nuanced examination of the evolutionary game relationships among the various stakeholders involved.

To sum up, existing research predominantly focuses on large-scale, well-established commercial platforms, with limited attention given to platforms offering user-paid quasi-public goods. Even when relevant studies exist, they often fail to distinguish the operational logic underlying these platforms from that of commercial platforms, lacking exploration into the issues of coordination among multiple stakeholders. This paper, taking IESP as a case study, innovatively examines the dynamic game among various stakeholders that support the construction, operation, and management of such platforms. Furthermore, we delve into how the government, as a facilitator, can promote stakeholders' engagement in value co-creation, ensuring the platform's sustainable development.

Three-party evolutionary game model

Model description

IESP is developed and operated collaboratively by multiple interdependent stakeholders, engaging in dynamic interactions and resource integration to achieve value co-creation. The long-term usage of IESP is the ultimate goal of these multi-stakeholder collaborations. To foster user engagement and ensure sustained usage of IESP, all stakeholders must actively contribute to value co-creation.

The digital technology company is responsible for continuously updating product designs, optimizing algorithms, and enhancing the intelligence of IESP to better accommodate the diverse needs of elderly users at various age stages. The social organization plays a crucial role in providing offline digital cognitive training, which is essential for helping older adults learn to use IESP effectively and for promoting its wider adoption. Additionally, the organization must enforce strict quality control measures for the elderly care service provider accessing the platform, ensuring that high-quality services are delivered to guarantee a positive user experience. Achieving these conditions simultaneously is critical for ensuring both the continued usage and sustainable development of IESP.

However, we recognize that the strategic behaviors of stakeholders may not always align with the overarching interests of IESP. For instance, the digital technology company, as IESP developer, may prioritize short-term profits, adopting a product-dominant logic that focuses on transactional value exchanges with the government. In this scenario, the completion of product delivery, as stipulated in contract, signifies the end of the transaction and the value relationship, with no involvement in subsequent platform iterations, upgrades, or other value co-creation activities aligned with a service-dominant logic. The social organization, potentially due to high operational costs, may refrain from conducting quality control over the elderly care service providers accessing IESP and may also lack enthusiasm in actively promoting IESP to the elderly. On the other hand, the elderly care service provider, concerned about the potential cost escalation associated with improving service quality, may attempt to skirt around these requirements, hoping to gain access to the platforms without enhancing their service standards.

To address these challenges and encourage continued usage of IESP, we have established a triadic evolutionary game model to study how to promote these stakeholders' participation in value co-creation.

Assumptions

This paper constructs a tripartite evolutionary game model and, considering the specific context of IESP in Shanghai, formulates the following assumptions.

Assumption 1 Due to constraints such as information asymmetry, the digital technology company, the social organization, and the eldercare service provider operate with bounded rationality. They continuously learn and adjust their strategies through repeated interactions, ultimately stabilizing their strategies at an optimal state.

Assumption 2 The probabilities of the digital technology company, the social organization, and the eldercare service provider choosing to participate in value co-creation are x, y and z respectively, while the probabilities of them choosing not to participate are $1-x$, $1-y$ and $1-z$, where $x, y, z \in [0, 1]$.

Assumption 3.1 When the digital technology company refrains from participating in value co-creation and merely fulfills the contract by delivering the product, it incurs basic development costs, denoted as C_d, and receives revenue from the government contract, denoted as G_d. However, due to the lack of involvement in subsequent platform maintenance and the absence of iterative adjustments based on user needs, this results in a suboptimal user experience and a poor brand image of IESP, ultimately leading to reputational losses, denoted as L_d, for the company both within the government sector and in the marketplace.

Assumption 3.2 When the digital technology company engages in value co-creation, it actively collates and analyzes user data to tailor interfaces for different age groups, provide personalized services, and enhance platform design. This approach improves user experience, leading to increased user activity and attracting more service providers to join the platform. If the social organization also participates in value co-creation, the service sales volume on IESP is defined as Q, with IESP charging a commission of I per unit sold, generating a commission income of IQ. This income is shared between them. The digital company's share of the revenue is defined as λ, where $\lambda \in (0, 1)$. When all parties choose to participate, a successful and user-approved IESP is established. The strong brand equity of IESP increases the digital technology company's visibility within the industry, facilitates the expansion of its market share, and results in reputational gains R_d. The act of participating in value co-creation incurs additional costs for the digital company, denoted as ΔC_d. If the social organization chooses not to participate, the sales volume on IESP decreases to ζQ $(\zeta \in (0, 1))$, and it becomes more difficult for the digital company to obtain operational data, raising the additional costs to $\beta \Delta C_d (\beta > 1)$. Moreover, if the elderly care service provider also opts out of participation, low-quality services may infiltrate the platform due to passive oversight by the social organization. This leads to a decline in user trust and engagement, reducing IESP sales volume to $\alpha\zeta Q$ and lowering the digital technology company's additional income to $\lambda\alpha\zeta IQ$, where $\alpha \in (0, 1)$.

Assumption 4.1 When the social organization does not engage in value co-creation, it incurs basic operational costs, denoted as C_s. Due to passive oversight of service quality and a lack of timely response to user feedback, which harm IESP's brand equity, the government receives an increased number of complaints, leading to reputational loss, denoted as L_s. Additionally, by not providing digital cognitive training for the elderly or actively promoting IESP, the sales volume on IESP decreases by a proportion of ζ. If the other two parties choose to participate, the elderly care services traded on the platform can still maintain high quality, with sales volume at ζQ. The social organization can obtain "free-rider" benefits, denoted as $(1-\lambda)\zeta Q$. However, if the digital company participates while the service provider does not, low-quality elderly care services enter the platform, reducing sales volume to $\alpha\zeta Q$ and diminishing the social organization's "free rider" benefits to $(1-\lambda)\alpha\zeta IQ$. If the digital company does not participate, the social organization is unable to promptly adjust the platform design based on market demands, resulting in a suboptimal user experience and a reduced sales volume, denoted as $\widetilde{Q}$. The social organization's choice not to participate further decreases the sales volume to $\zeta\widetilde{Q}$. Consequently, the commission income generated on IESP, amounting to $\zeta I\widetilde{Q}$, is entirely received by the social organization, where $\zeta I\widetilde{Q} < (1-\lambda) IQ$. In the scenario where neither the digital company nor service provider engage, the revenue of the social organization operating IESP diminishes to $\alpha\zeta I\widetilde{Q}$.

Assumption 4.2 When the social organization chooses to engage in value co-creation, it incurs additional operational costs, denoted as ΔC_s. The social organization's participation provides digital cognitive training to help elderly users overcome the digital divide and ensures that the elderly care service providers on the platform meet quality standards. If the digital technology company also participates, IESP achieves higher service sales volume Q, and the social organization's allocated revenue is $(1-\lambda) IQ$. If the digital technology company does not participate, the revenue is $I\widetilde{Q}$ ($I\widetilde{Q} < (1-\lambda) IQ$). When all three parties choose to participate, the strong brand equity of IESP leads to a higher rating for the social organization from the government, resulting in more favorable policies and opportunities for project management, thereby yielding reputational benefits, denoted as R_s.

Assumption 5.1 When the elderly care service provider does not engage in value co-creation, it offers low-quality services at a cost of C_{pL} and generates offline sales revenue of R_{pL}. If the social organization also opts not to participate, the provider gain access to the online platform, incurring digital transformation cost, denoted as C_p. In this scenario, if the digital technology company chooses to participate, it can analyze data to identify and promote popular, high-quality service provider, thereby reducing the visibility of low-quality provider, who would then see only a marginal increase in online order revenue, denoted as ΔR_{pL}. However, if the digital technology company does not participate, the service provider can achieve an increased online revenue of ΔR_p, where $\Delta R_p > \Delta R_{pL}$.

Assumption 5.2 When the service provider engages in value co-creation, it offers high-quality services at a cost of C_{pH} and generates offline sales revenue of R_{pH}. The digital transformation cost is denoted as C_p. If the digital technology company opt to participate, the service provider will receive higher recommendation ratings due to its superior service quality, allowing it to capture a larger market share and increase online revenue to $\Delta R_{pH}, \Delta R_{pH} > \Delta R_p$. If the social organization also chooses to participate, it will rigorously assess the quality level of the service provider, enabling high-quality provider to receive government subsidy for smart upgrades, denoted as G_p.

The logical relationships among the three parties under the above hypotheses are depicted in Figure 1.

Game payoff matrix

The symbols and meanings of all parameter variables are detailed in Table 1. We construct the payoff matrix for the game among the three key players: the digital technology company, the social organization, and the elderly care service provider, as shown in Table 2. Each cell signifies a different strategy combination for these players. The first formula in each cell indicates the payoff function of the digital technology company, the second represents the social organization, and the third pertains to the elderly care service provider.

Analysis of the evolutionary game model

Strategic stability of the digital technology company

The expected revenues (E_{11}, E_{12}) for the digital technology company when participating and not participating in value co-creation, as well as the average expected revenue ($\overline{E_1}$) are as follows:

$$\begin{cases} E_{11} = yz\left(G_d + R_d + \lambda IQ - C_d - \Delta C_d\right) + y\left(1-z\right)\left(G_d + \lambda IQ - C_d - \Delta C_d\right) \\ +\left(1-y\right)z\left(G_d + \lambda\zeta IQ - C_d - \beta\Delta C_d\right) + \left(1-y\right)\left(1-z\right)\left(G_d + \lambda\alpha\zeta IQ - C_d - \beta\Delta C_d\right) \\ E_{12} = yz\left(G_d - C_d - L_d\right) + y\left(1-z\right)\left(G_d - C_d - L_d\right) \\ +\left(1-y\right)z\left(G_d - C_d - L_d\right) + \left(1-y\right)\left(1-z\right)\left(G_d - C_d - L_d\right) \\ \overline{E_1} = xE_{11} + \left(1-x\right)E_{12} \end{cases} \tag{1}$$

The replicator dynamic equation is expressed as:

$$F\left(x\right) = \frac{dx}{dt} = x\left(E_{11} - \overline{E_1}\right) = x\left(1-x\right)\begin{pmatrix} L_d - \Delta C_d\beta + \left(\beta-1\right)\Delta C_d y + R_d yz \\ +IQ\lambda\left(\alpha\zeta + y\left(1-\alpha\zeta\right) + \left(1-\alpha\right)\left(1-y\right)\zeta z\right) \end{pmatrix} \tag{2}$$

We obtain the first-order derivative of the replicator dynamic equation with respect to x.

$$\frac{dF\left(x\right)}{dx} = \left(2x-1\right)G\left(z\right) \tag{3}$$

where $G\left(z\right) = -L_d + \Delta C_d\beta + \left(\beta-1\right)\Delta C_d y - R_d yz - IQ\lambda\left(\alpha\zeta + y\left(1-\alpha\zeta\right) + \left(1-\alpha\right)\left(1-y\right)\zeta z\right)$.

According to the stability theorem of differential equations, the strategic equilibrium points of the digital technology company must satisfy $F\left(x\right) = 0$ and $dF\left(x\right)/dx < 0$. It can be deduced that $\partial G\left(z\right)/\partial z = \lambda\zeta IQ\left(1-y\right)\left(\alpha-1\right) - R_d y < 0$, implying that $G\left(z\right)$ is a decreasing function of z. We can derive $G\left(z\right) = 0$ when $z = z_1^* = \frac{\Delta C_d\left(\left(1-y\right)\beta + y\right) - L_d - IQ\lambda\left(\alpha\zeta\left(1-y\right) + y\right)}{R_d y + \lambda\zeta IQ\left(y-1\right)\left(\alpha-1\right)}$, at which point $dF\left(x\right)/dx \equiv 0$, rendering it indeterminate for the digital technology company to ascertain a stable strategy. When $z < z_1^*$, we derive $G\left(z\right) > 0$ and $\left.\frac{dF(x)}{dx}\right|_{x=0} < 0$, in which case $x = 0$ becomes the evolutionary stable strategy (ESS) for

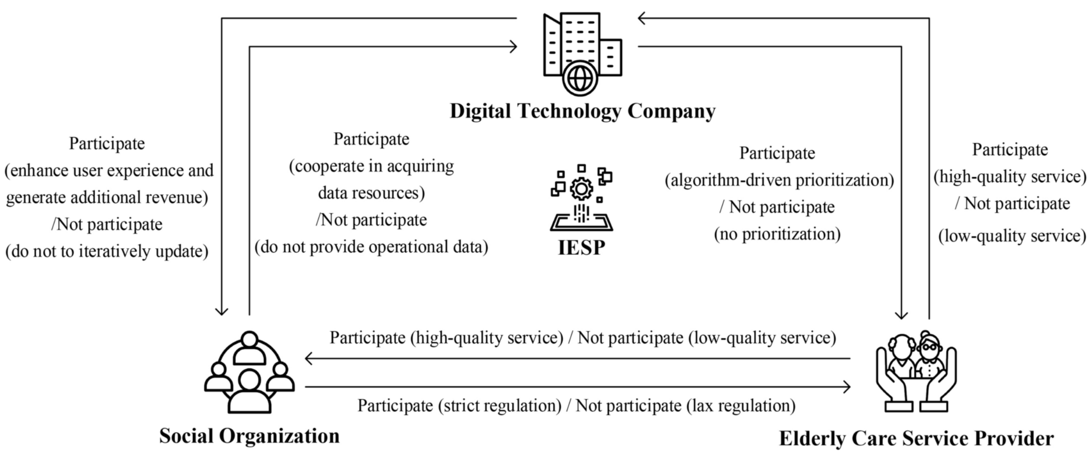


Fig. 1. Logical relationship diagram of the tripartite evolutionary game model.

Parameter	
Q	The highest sales volume of services on IESP
$\widetilde{Q}$	The highest sales volume of services on IESP when the digital company does not participate
I	Commission taken by IESP per unit of sale
ζ	Reduction coefficient of IESP sales volume when the social organization does not provide digital cognitive training for the elderly
α	Reduction coefficient of IESP sales volume when low-quality service provider enters IESP
Digital Technology Company	
G_d	Government contract payments received for IESP development
C_d	Costs incurred for IESP development
L_d	Reputational loss due to non-participation in value co-creation
ΔC_d	Additional costs incurred for participating in value co-creation
β	Additional cost coefficient incurred by the company when it participates in value co-creation while the social organization does not participate
λ	Share of IESP commission received by the company when it participates in value co-creation
R_d	Reputational gains obtained by the company when all three parties simultaneously engage in value co-creation
Social Organization	
C_s	Basic operational costs incurred when not participating in value co-creation
L_s	Reputational loss due to non-participation in value co-creation
$1-\lambda$	Share of IESP commission received by the social organization when digital technology company participates in value co-creation
ΔC_s	Additional costs incurred for participating in value co-creation
R_s	Reputational gains obtained by the social organization when all three parties simultaneously engage in value co-creation
Elderly Care Service Provider	
C_{pH}	Service costs when participating in value co-creation
R_{pH}	Offline revenue generated from high-quality services
C_{pL}	Service costs when not participating in value co-creation
R_{pL}	Offline revenue generated from low-quality services
C_p	Digital transformation costs incurred for joining the platform
ΔR_p	Increased revenue from online orders when the digital technology company does not participate in value co-creation
ΔR_{pH}	Increased revenue from online orders when both the service provider and the digital technology company participate in value co-creation
ΔR_{pL}	Increased revenue from online orders when the digital technology company participates while the service provider does not
G_p	Government subsidies received by the service provider when both the service provider and the social organization participate in value co-creation

Table 1. Notations for the model.

Strategy selection		**Digital Technology Company Participate** (x)	**Digital Technology Company Not participate** $(1-x)$
Social Organization Participate (y)	Service Provider Participate (z)	$G_d + R_d + \lambda IQ - C_d - \Delta C_d$, $(1-\lambda)IQ + R_s - C_s - \Delta C_s$, $R_{pH} - C_{pH} + G_p + \Delta R_{pH} - C_p$	$G_d - C_d - L_d$, $I\widetilde{Q} - C_s - \Delta C_s$, $R_{pH} - C_{pH} + G_p + \Delta R_p - C_p$
	Service Provider Not Participate $(1-z)$	$G_d + \lambda IQ - C_d - \Delta C_d$, $(1-\lambda)IQ - C_s - \Delta C_s$, $R_{pL} - C_{pL}$	$G_d - C_d - L_d$, $I\widetilde{Q} - C_s - \Delta C_s$, $R_{pL} - C_{pL}$
Social Organization Not Participate $(1-y)$	Service Provider Participate (z)	$G_d + \lambda\zeta IQ - C_d - \beta\Delta C_d$, $(1-\lambda)\zeta IQ - C_s - L_s$, $R_{pH} - C_{pH} + \Delta R_{pH} - C_p$	$G_d - C_d - L_d$, $\zeta I\widetilde{Q} - C_s - L_s$, $R_{pH} - C_{pH} + \Delta R_p - C_p$
	Service Provider Not Participate $(1-z)$	$G_d + \lambda\alpha\zeta IQ - C_d - \beta\Delta C_d$, $(1-\lambda)\alpha\zeta IQ - C_s - L_s$, $R_{pL} - C_{pL} + \Delta R_{pL} - C_p$	$G_d - C_d - L_d$, $\alpha\zeta I\widetilde{Q} - C_s - L_s$, $R_{pL} - C_{pL} + \Delta R_p - C_p$

Table 2. Payoff matrix of the evolutionary game model.

the digital technology company. Conversely, when $z > z_1^*$, we obtain $G(z) < 0$ and $\left.\frac{dF(x)}{dx}\right|_{x=1} < 0$, meaning that $x = 1$ is ESS. The phase diagram for the strategy evolution of the digital technology company is shown in Fig. 2.

Proposition 1: *During the evolutionary process, the probability of the digital technology company choosing to participate in value co-creation increases as the participation probabilities of the other two parties rise.*

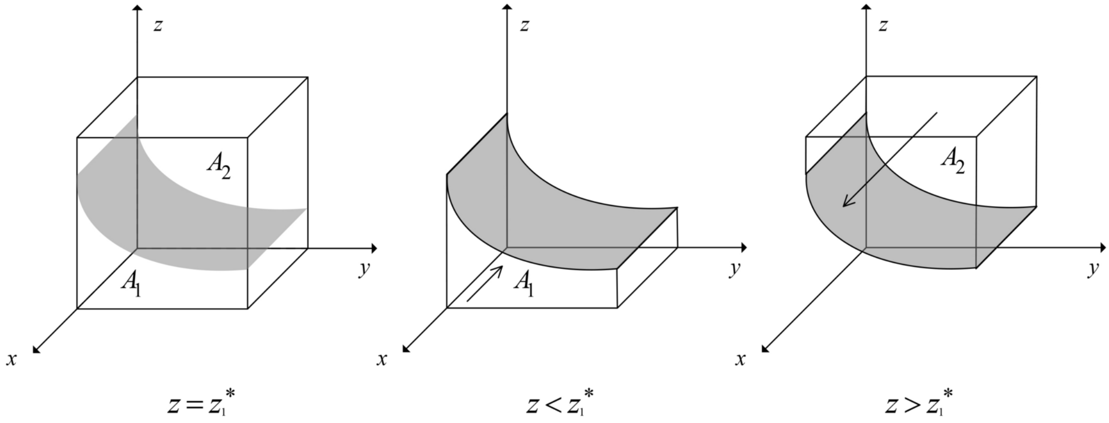


Fig. 2. The phase diagram of the strategy evolution for the digital technology company.

Proposition 1 indicates that the more actively the social organization operates and the stronger the service provider's commitment to delivering high-quality services, the more inclined the digital technology company is to engage in value co-creation. Conversely, if the social organization neglects to provide digital training for the elderly, fails to promptly respond to their feedback, does not cooperate in the integration of digital resources, and exercises lax oversight over the service provider—allowing low-quality provider to access IESP—trust in IESP among the elderly diminishes. This erosion of trust leads to reduced user engagement and consequently lowers IESP's revenue. In such a scenario, the digital technology company has little incentive to participate in value co-creation activities, such as iterative IESP updates. Therefore, for the sustainable development of IESP, it is imperative that the government strengthens oversight of the social organization's operational behavior and establishes a quality standard and evaluation system for the elderly care service provider.

Proposition 2: *The probability of the digital technology company opting to engage in value co-creation strategy is positively correlated with the benefits derived from IESP (IQ), reputational gains (R_d), and reputational loss incurred from non-participation (L_d). Conversely, it is negatively correlated with the additional costs associated with value co-creation (ΔC_d).*

Proposition 2 indicates that increasing the revenue generated by IESP and reducing the additional operational costs for the digital technology company will encourage its participation in value co-creation. To achieve this, the government should enhance the promotion of IESP by collaborating with grassroots organizations, such as neighborhood committees and community councils, to carry out offline campaigns that bridge the digital divide among the elderly, thereby increasing the number of active users on IESP and achieving economies of scale. Additionally, the government can incentivize the digital technology company to engage in value co-creation by lowering the cost of data acquisition. This can be done by opening public data, establishing data-sharing platforms, and developing and promoting data standards. Moreover, both reputational gains and losses can motivate the digital technology company to participate in value co-creation. Thus, the government should prioritize subsequent collaborations with companies that actively engage in value co-creation. Conversely, for companies that fail to cooperate in maintenance after project acceptance, the government should reduce their opportunities for future collaboration.

Strategic stability of the social organization

The expected revenues (E_{21}, E_{22}) for the social organization when participating and not participating in value co-creation, as well as the average expected revenue ($\overline{E_2}$) are as follows:

$$\left\{\begin{array}{l} E_{21}=xz\left(\left(1-\lambda\right)IQ+R_s-C_s-\Delta C_s\right)+\left(1-x\right)z\left(I\widetilde{Q}-C_s-\Delta C_s\right)\\ +x\left(1-z\right)\left(\left(1-\lambda\right)IQ-C_s-\Delta C_s\right)+\left(1-x\right)\left(1-z\right)\left(I\widetilde{Q}-C_s-\Delta C_s\right)\\ E_{22}=xz\left(\left(1-\lambda\right)\zeta IQ-C_s-L_s\right)+\left(1-x\right)z\left(\zeta I\widetilde{Q}-C_s-L_s\right)\\ +x\left(1-z\right)\left(\left(1-\lambda\right)\alpha\zeta IQ-C_s-L_s\right)+\left(1-x\right)\left(1-z\right)\left(\alpha\zeta I\widetilde{Q}-C_s-L_s\right)\\ \overline{E_2}=yE_{21}+\left(1-y\right)E_{22} \end{array}\right. \tag{4}$$

The replicator dynamic equation is expressed as:

$$F\left(y\right)=\frac{dy}{dt}=y\left(E_{21}-\overline{E_{2}}\right)$$
$$=y\left(1-y\right)\begin{pmatrix}L_{s}-\Delta C_{s}+I\widetilde{Q}\left(1-\alpha\zeta\right)+\left(IQ\left(1-\lambda\right)-I\widetilde{Q}\right)\left(1-\alpha\zeta\right)x-I\widetilde{Q}\left(1-\alpha\right)\zeta z\\+\left(I\widetilde{Q}\left(1-\alpha\right)+\left(\lambda-1\right)\left(1-\alpha\right)IQ\right)\zeta xz+R_{s}xz\end{pmatrix} \quad (5)$$

The first-order derivative of the replicator dynamic equation with respect to y is derived as:

$$\frac{dF\left(y\right)}{dy}=\left(2y-1\right)H\left(z\right) \quad (6)$$

where

$$H\left(z\right)=-L_{s}+\Delta C_{s}-I\widetilde{Q}\left(1-\alpha\zeta\right)-\left(IQ\left(1-\lambda\right)-I\widetilde{Q}\right)\left(1-\alpha\zeta\right)x+I\widetilde{Q}\left(1-\alpha\right)\zeta z-\left(I\widetilde{Q}\left(1-\alpha\right)+\left(\lambda-1\right)\left(1-\alpha\right)IQ\right)\zeta xz-R_{s}xz.$$

Through a similar solving process, we obtain $H\left(z\right)=0$ when $z=z_{2}^{*}=\frac{\left(IQ(1-\lambda)-I\widetilde{Q}\right)(1-\alpha\zeta)x+I\widetilde{Q}(1-\alpha\zeta)+L_{s}-\Delta C_{s}}{I\widetilde{Q}\zeta(1-\alpha)(1-x)-((\lambda-1)(1-\alpha)IQ\zeta+R_{s})x}$, at which point $dF\left(y\right)/dy\equiv0$, meaning that the social organization cannot determine a stable strategy, as illustrated in Fig. 3(a). There exist two possible stable states, $y=0$ or $y=1$, when $z\neq z_{2}^{*}$.

When $\frac{\partial H(z)}{\partial z}>0$:

- If $z<z_{2}^{*}$, it follows that $\left.\frac{dF(y)}{dy}\right|_{y=1}<0$, and $y=1$ is ESS, as illustrated by arrow (2) in Fig. 3(b).
- If $z>z_{2}^{*}$, it follows that $\left.\frac{dF(y)}{dy}\right|_{y=0}<0$, and $y=0$ is ESS, as illustrated by arrow (1) in Fig. 3(c).

When $\frac{\partial H(z)}{\partial z}<0$:

- If $z<z_{2}^{*}$, it follows that $\left.\frac{dF(y)}{dy}\right|_{y=0}<0$, and $y=0$ is ESS, as illustrated by arrow (1) in Fig. 3(b).
- If $z>z_{2}^{*}$, it follows that $\left.\frac{dF(y)}{dy}\right|_{y=1}<0$, and $y=1$ is ESS, as illustrated by arrow (2) in Fig. 3(c).

Through the above calculations, we can obtain the Proposition 3.

Proposition 3: *If* $R_{s}>IQ\left(1-\lambda\right)\left(1-\alpha\right)\zeta$ *and* $x>x_{1}^{*}=\frac{I\widetilde{Q}\zeta(1-\alpha)}{I\widetilde{Q}(1-\alpha)\zeta+R_{s}-IQ(1-\lambda)(1-\alpha)\zeta}$ *are both met,* $\frac{\partial H(z)}{\partial z}<0$. *Otherwise,* $\frac{\partial H(z)}{\partial z}>0$.

Proposition 3 indicates that if the reputational gains acquired by the social organization outweigh its losses incurred from low-quality service provider entering IESP, then the probability of the social organization participating in value co-creation increases as the probability of the service provider's participation increases, provided that the digital technology company's participation probability exceeds a certain threshold. Otherwise, the probability of the organization participating decreases as the probability of the service provider's participation rises.

Thus, the reputational gains of the social organization serve as a pivotal factor in determining the full engagement of all stakeholders in value co-creation. This is rooted in the fact that the reputational gains are only achievable when all three parties actively participate in value co-creation, leading to the successful establishment

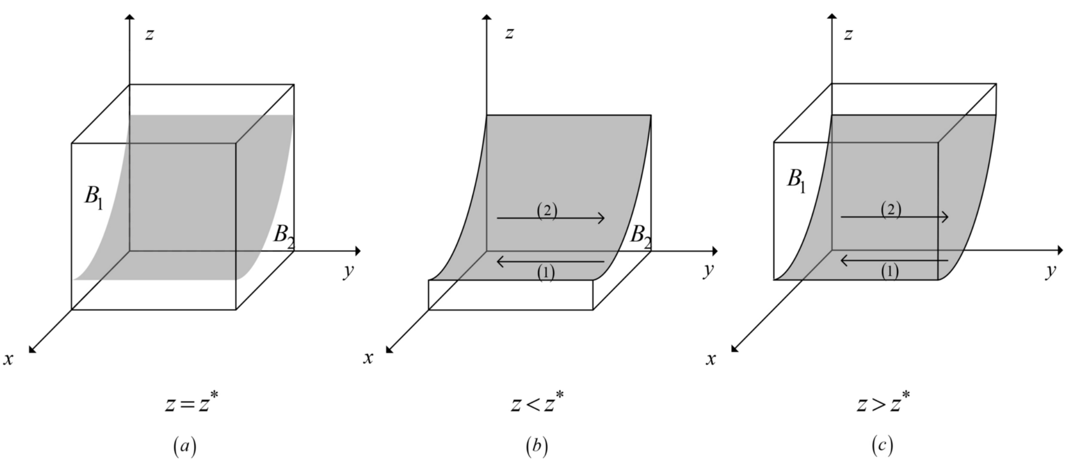


Fig. 3. The phase diagram of the strategy evolution for the social organization.

of a high-satisfaction IESP. Such active involvement allows the social organization to achieve superior operational performance metrics, resulting in higher government ratings and more favorable policies. When reputational gains are substantial, even if the service provider is likely to offer high-quality services, the social organization remains motivated to enforce strict regulations, ensuring that no low-quality provider gains access to IESP. Conversely, when reputational gains are insufficient, the social organization may opt for relaxed oversight when the service provider tends to deliver high-quality services, thus reducing operational costs and exhibiting "free-rider" behavior. Therefore, the government must rigorously assess the ratings of social organizations and offer more favorable policies to those with higher ratings.

Strategic stability of the elderly care service provider

The expected revenues (E_{31}, E_{32}) for the service provider when participating and not participating in value co-creation, as well as the average expected revenue ($\overline{E_3}$) are as follows:

$$\begin{cases} E_{31} = xy\left(R_{pH} - C_{pH} + G_p + \Delta R_{pH} - C_p\right) + (1-x)\,y\left(R_{pH} - C_{pH} + G_p + \Delta R_p - C_p\right) \\ \quad +x\,(1-y)\left(R_{pH} - C_{pH} + \Delta R_{pH} - C_p\right) + (1-x)(1-y)\left(R_{pH} - C_{pH} + \Delta R_p - C_p\right) \\ E_{32} = xy\left(R_{pL} - C_{pL}\right) + (1-x)\,y\left(R_{pL} - C_{pL}\right) \\ +x\,(1-y)\left(R_{pL} - C_{pL} + \Delta R_{pL} - C_p\right) + (1-x)(1-y)\left(R_{pL} - C_{pL} + \Delta R_p - C_p\right) \\ \overline{E_3} = zE_{31} + (1-z)\,E_{32} \end{cases} \tag{7}$$

The replicator dynamic equation is expressed as:

$$F(z) = \frac{dz}{dt} = z\left(E_{31} - \overline{E_3}\right) = z\,(1-z)\begin{pmatrix} C_{pL} - C_{pH} + R_{pH} - R_{pL} + \left(\Delta R_{pH} - \Delta R_{pL}\right)x \\ +\left(\Delta R_p + G_p - C_p\right)y + \left(\Delta R_{pL} - \Delta R_p\right)xy \end{pmatrix} \tag{8}$$

The first-order derivative of the replicator dynamic equation with respect to z is derived as:

$$\frac{dF(z)}{dz} = (2z-1)\,J(x) \tag{9}$$

where $\begin{array}{l} J(x) = -C_{pL} + C_{pH} - R_{pH} + R_{pL} - \left(\Delta R_{pH} - \Delta R_{pL}\right)x \\ \quad - \left(\Delta R_p + G_p - C_p\right)y - \left(\Delta R_{pL} - \Delta R_p\right)xy \end{array}$.

Through the similar solving process, we obtain $J(x) = 0$ when $x = x^* = \frac{-C_{pL} + C_{pH} - R_{pH} + R_{pL} - \left(\Delta R_p + G_p - C_p\right)y}{\Delta R_{pH} - \Delta R_{pL} + \left(\Delta R_{pL} - \Delta R_p\right)y}$, at which point $dF(z)/dz \equiv 0$, indicating that the service provider is unable to determine a stable strategy. It can be deduced that $\frac{\partial J(x)}{\partial x} = \Delta R_{pL} - \Delta R_{pH} + \left(\Delta R_p - \Delta R_{pL}\right)y < 0$. When $x < x^*$, we derive $J(x) > 0$ and $\left.\frac{dF(z)}{dz}\right|_{z=0} < 0$, in which case $z = 0$ becomes ESS for the service provider. Conversely, when $x > x^*$, we obtain $\left.\frac{dF(z)}{dz}\right|_{z=1} < 0$

, meaning that $z = 1$ is ESS. The phase diagram for the strategy evolution of the service provider is shown in Fig. 4.

Proposition 4: *During the evolutionary process, the probability of the elderly care service provider opting to engage in value co-creation increases as the participation probabilities of the other two parties rise.*

Proposition 4 indicates that the stronger the willingness of the digital technology company and social organization to engage in value co-creation, the more inclined the elderly care service provider is to offer high-quality services. This is because when the digital technology company participates in value co-creation, it enhances the visibility of high-quality service provider by analyzing user feedback data, thereby widening the gap in market share and revenue between high-quality and low-quality service providers. Additionally, when the social organization imposes strict oversight on service provider, low-quality service providers are precluded from accessing IESP, depriving them of online customer acquisition opportunities. Therefore, increasing policy incentives for the digital technology company and social organization that participate in value co-creation can effectively encourage the elderly care service provider to improve service quality.

Proposition 5: *The probability of the elderly care service provider opting to engage in value co-creation strategies is positively correlated with the additional revenue generated by improving service quality ($R_{pH} - R_{pL}$, $\Delta R_{pH} - \Delta R_{pL}$) and government subsidies (G_p), and negatively correlated with the costs of digital transformation for joining the platform (C_p) and the additional costs incurred in enhancing service quality ($C_{pH} - C_{pL}$).*

Proposition 5 indicates that the service provider is incentivized to offer high-quality services only when improving service quality leads to higher profits. Therefore, enhancing the payment capacity of the elderly is a fundamental approach to improving the service quality. Additionally, the government can widen the income gap between high-quality and low-quality service providers by standardizing rating criteria and increasing incentives and financial subsidies for high-quality providers. For example, policies like the "reward instead of subsidy" initiative introduced by Shanghai can be effective.

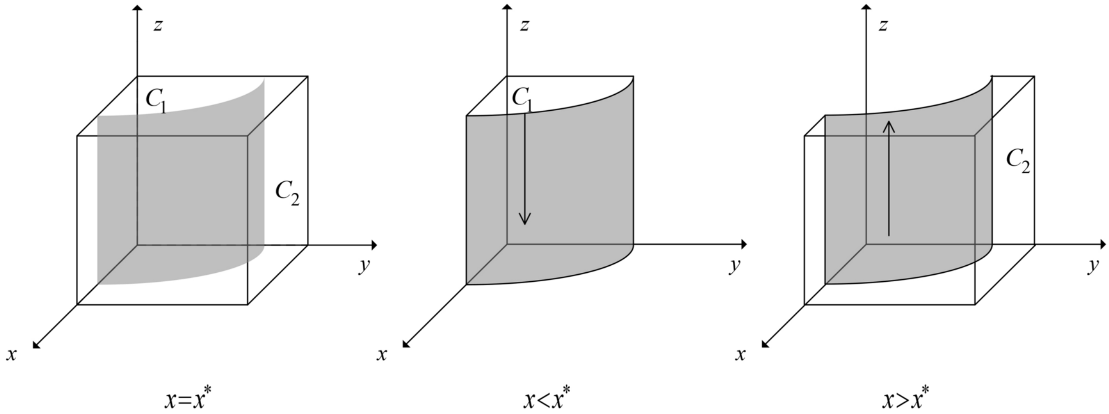


Fig. 4. The phase diagram of the strategy evolution for the service provider.

Stability analysis of the system's equilibrium strategies

Considering that the strategy set in this binary-choice game consists of participation or non-participation, we focus exclusively on the analysis of pure strategies. This approach is chosen to facilitate practical application and understanding, which is supported by many research findings[54,55]. From $F(x) = 0$, $F(y) = 0$ and $F(z) = 0$, we can derive eight possible strategy combinations, namely $(0,0,0)$, $(1,0,0)$, $(0,1,0)$, $(1,1,0)$, $(0,0,1)$, $(0,1,1)$, $(1,0,1)$ and $(1,1,1)$. To determine the system's equilibrium strategies, we first construct the Jacobian matrix, following the approach outlined by Friedman[56].

$$J = \begin{bmatrix} \partial F(x)/\partial x & \partial F(x)/\partial y & \partial F(x)/\partial z \\ \partial F(y)/\partial x & \partial F(y)/\partial y & \partial F(y)/\partial z \\ \partial F(z)/\partial x & \partial F(z)/\partial y & \partial F(z)/\partial z \end{bmatrix} = \begin{bmatrix} J_{11} & J_{12} & J_{13} \\ J_{21} & J_{22} & J_{23} \\ J_{31} & J_{32} & J_{33} \end{bmatrix}$$

where

$$J_{11} = (2x-1)\left(-L_d + \Delta C_d \beta + (\beta-1)\Delta C_d y - R_d y z - IQ\lambda\left(\alpha\zeta + y(1-\alpha\zeta) + (1-\alpha)(1-y)\zeta z\right)\right)$$

,

$$J_{12} = x(1-x)\left((\beta-1)\Delta C_d + IQ\lambda\left(1-\alpha\zeta + (\alpha-1)z\zeta\right) + R_d z\right)$$

,

$$J_{13} = x(1-x)\left(IQ\zeta\lambda(1-\alpha)(1-y) + R_d y\right),$$

$$J_{21} = y(1-y)\left(\left(IQ(1-\lambda) - I\widetilde{Q}\right)(1-\alpha\zeta) + \left(I\widetilde{Q}(1-\alpha) + (\lambda-1)(1-\alpha)IQ\right)z\zeta + R_s z\right)$$

,

$$J_{22} = (2y-1)\begin{pmatrix} -L_s + \Delta C_s - I\widetilde{Q}(1-\alpha\zeta) - \left(IQ(1-\lambda) - I\widetilde{Q}\right)(1-\alpha\zeta)x + I\widetilde{Q}(1-\alpha)\zeta z \\ -\left(I\widetilde{Q}(1-\alpha) + (\lambda-1)(1-\alpha)IQ\right)\zeta x z - R_s x z \end{pmatrix}$$

,

$$J_{23} = y(1-y)\left(-I\widetilde{Q}\zeta(1-\alpha) + \left(I\widetilde{Q}(1-\alpha) + (\lambda-1)(1-\alpha)IQ\right)x\zeta + R_s x\right)$$

,

$$J_{31} = z(1-z)\left(\Delta R_{pH} - \Delta R_{pL} + (\Delta R_{pL} - \Delta R_p)y\right)$$

,

$$J_{32} = z(1-z)\left(\Delta R_p + G_p - C_p + (\Delta R_{pL} - \Delta R_p)x\right),$$

$$J_{33} = (2z-1)\left(-C_{pL} + C_{pH} - R_{pH} + R_{pL} - (\Delta R_{pH} - \Delta R_{pL})x - (\Delta R_p + G_p - C_p)y - (\Delta R_{pL} - \Delta R_p)xy\right)$$

.

According to Lyapunov's system stability theory, an equilibrium point can be determined as an ESS if all the eigenvalues of the Jacobian matrix have negative real parts. The stability analysis of the strategy combinations is presented in Table 3.

Proposition 6: *If $D_2 < 0$, it can be inferred that $D_1 > 0$, $D_3 > 0$, $D_4 > 0$,$D_6 > 0$, $D_5 < 0$, $D_7 < 0$ and $D_8 < 0$.*

Corollary 6 indicates that when $D_2 < 0$ is satisfied, the digital technology company's stable equilibrium strategy in pure strategy combinations will always be to engage in value co-creation, regardless of the choices made by the other two parties. This is because $D_2 < 0$ represents the minimum additional benefit that the digital technology company can obtain by participating in value co-creation (the additional benefit gained when the digital company chooses to participate while the other two parties do not), which still exceeds the loss incurred if it does not participate. Notably, reducing the operational costs incurred by the digital company's participation, increasing the sales volume and commission on IESP, as well as the profit distribution ratio for the digital company, and enhancing the reputational damage suffered by the digital company when it chooses not to participate, can all contribute to the fulfillment of $D_2 < 0$.

Strategy combination	Jacobian matrix eigenvalues $\lambda_1, \lambda_2, \lambda_3$	Conditions for ESS
$(0, 0, 0)$	$D_1 = L_d - \Delta C_d \beta + \zeta IQ\alpha\lambda$, $S_1 = L_s - \Delta C_s + IQ(1 - \alpha\zeta)$, $P_1 = R_{pH} - C_{pH} - (R_{pL} - C_{pL})$,	Condition 1 $D_1 < 0, S_1 < 0, P_1 < 0$
$(1, 0, 0)$	$D_2 = \Delta C_d \beta - L_d - \zeta IQ\alpha\lambda$, $S_2 = L_s - \Delta C_s + IQ(1 - \alpha\zeta)(1 - \lambda)$, $P_2 = R_{pH} - C_{pH} - (R_{pL} - C_{pL}) + \Delta R_{pH} - \Delta R_{pL}$	Condition 2 $D_2 < 0, S_2 < 0, P_2 < 0$
$(0, 1, 0)$	$D_3 = L_d - \Delta C_d + IQ\lambda$, $S_3 = \Delta C_s - L_s - IQ(1 - \alpha\zeta)$, $P_3 = R_{pH} - C_{pH} - (R_{pL} - C_{pL}) + \Delta R_p + G_p - C_p$	Condition 3 $D_3 < 0, S_3 < 0, P_3 < 0$
$(0, 0, 1)$	$D_4 = L_d - \Delta C_d \beta + \zeta IQ\lambda$, $S_4 = L_s - \Delta C_s + IQ(1 - \zeta)$, $P_4 = R_{pL} - C_{pL} - (R_{pH} - C_{pH})$	Condition 4 $D_4 < 0, S_4 < 0, P_4 < 0$
$(1, 1, 0)$	$D_5 = \Delta C_d - L_d - IQ\lambda$, $S_5 = \Delta C_s - L_s - IQ(1 - \alpha\zeta)(1 - \lambda)$, $P_5 = R_{pH} - C_{pH} - (R_{pL} - C_{pL}) + \Delta R_{pH} + G_p - C_p$	Condition 5 $D_5 < 0, S_5 < 0, P_5 < 0$
$(0, 1, 1)$	$D_6 = L_d - \Delta C_d + R_d + IQ\lambda$, $S_6 = \Delta C_s - L_s + IQ(\zeta - 1)$, $P_6 = R_{pL} - C_{pL} - (R_{pH} - C_{pH}) - (\Delta R_p + G_p - C_p)$	Condition 6 $D_6 < 0, S_6 < 0, P_6 < 0$
$(1, 0, 1)$	$D_7 = \Delta C_d \beta - L_d - \zeta IQ\lambda$, $S_7 = L_s - \Delta C_s + R_s + IQ(1 - \lambda)(1 - \zeta)$, $P_7 = R_{pL} - C_{pL} - (R_{pH} - C_{pH}) - (\Delta R_{pH} - \Delta R_{pL})$	Condition 7 $D_7 < 0, S_7 < 0, P_7 < 0$
$(1, 1, 1)$	$D_8 = \Delta C_d - L_d - R_d - IQ\lambda$, $S_8 = \Delta C_s - L_s - R_s - IQ(1 - \zeta)(1 - \lambda)$, $P_8 = R_{pL} - C_{pL} - (R_{pH} - C_{pH}) - (\Delta R_{pH} + G_p - C_p)$	Condition 8 $D_8 < 0, S_8 < 0, P_8 < 0$

Table 3. Stability analysis of strategy combinations.

Proposition 7: *If $S_6 < 0$, it can be inferred that $S_1 > 0$, $S_2 > 0$, $S_4 > 0$, $S_7 > 0$, $S_3 < 0$, $S_5 < 0$ and $S_8 < 0$.*

Proposition 7 suggests that when $S_6 < 0$ condition is met, regardless of the choices made by the other two parties, the stable equilibrium strategy for the social organization in a pure strategy combination is to participate in value co-creation. Unlike the digital technology company, the minimum likelihood for the social organization to engage in value co-creation does not arise when the other two parties are absent, but rather when the service provider participates while the digital technology company does not. This is evident in the fact that $S_3 < 0$ is more relaxed than $S_6 < 0$. When the service provider actively participates in value co-creation by offering high-quality services, the social organization's lack of stringent supervision does not negatively impact IESP's reputation or reduce its revenue, making the incentive for the social organization to participate in value co-creation lower than when the service provider does not participate. When the condition $S_6 < 0$ is met, ensuring that the social organization's benefits from participating in value co-creation exceed those of not participating, the organization will invariably choose to engage in value co-creation. As IESP sales increase through digital cognitive training, the extra costs of participating in value co-creation decrease, and the reputation loss for not participating grows, making it easier to meet condition $S_6 < 0$.

Proposition 8: *If $P_4 < 0$, it can be inferred that $P_1 > 0$, $P_2 > 0$ and $P_7 < 0$. If $P_6 < 0$, it can be inferred that $P_3 > 0$, $P_5 > 0$ and $P_8 < 0$. When $\Delta R_p + G_p - C_p > 0$, $P_4 < 0$ implies $P_6 < 0$.*

Proposition 8 demonstrates that when the digital technology company engages in value co-creation, the constraints required to achieve the service provider's participation in value co-creation are more relaxed than when the digital company does not participate. This implies that the involvement of the digital company can encourage the service provider to adopt a participatory strategy. Specifically, when the sum of the minimum online income earned by the high-quality service provider and government subsidies exceeds its digital transformation costs (i.e., $\Delta R_p + G_p - C_p > 0$), $P_4 < 0$ can deduce $P_6 < 0$, suggesting that the participation of the social organization can motivate the service provider to choose a participatory strategy. This is because, under such conditions, the service provider has the incentive to join IESP, and the rigorous supervision of the social organization makes delivering high-quality services a prerequisite for the service provider to access IESP. Conversely, when the digital transformation costs for the service provider are higher, the provider lacks the motivation to join IESP. Therefore, in addition to increasing the profit margin between high-quality and low-quality offline services to satisfy the condition $P_4 < 0$, it is also crucial to enhance the service provider's online revenue, increase government subsidies for high-quality service providers, and reduce the digital transformation costs for the service provider.

Proposition 9: *When Condition 8 is satisfied, the system reaches an ideal state, where the evolutionarily stable strategy for all three parties is to engage in value co-creation. Additionally, Condition 2 and Condition 8 may coexist, as may Conditions 3, 4, and 8. To ensure that the system evolves toward the ideal state, i.e., to ensure that only Condition 8 is satisfied, it is necessary to maximize R_d, R_s, G_p and ΔR_{pH}, while minimizing C_p.*

We can find that, compared to the strictest constraints outlined in Proposition 6 to 8 that compel a single party to engage in value co-creation, the constraints in Condition 8 are somewhat relaxed in achieving the participation of all parties in value co-creation. This implies that when all three parties choose to engage in co-creation, a win-win situation can be realized. To achieve this ideal state, it is necessary to enhance the reputational benefits for the digital technology company and the social organization, increase subsidies for high-quality service providers, widen the income gap between high-quality and low-quality service providers, and reduce the digital transformation costs for the service providers.

Numerical simulation analysis

This section conducts numerical experiments to validate the theoretical analysis and to explore further managerial implications. The parameter settings are referenced from the bid announcement for IESP in Pudong New Area, Shanghai, the document No. [2022] 1079 issued by the Pudong Development and Reform Commission, the contract for technology-assisted elderly information services by the Pudong New Area Civil Affairs Bureau, and the notice from the Shanghai Municipal Finance Bureau regarding funding support for the construction of smart elderly care facilities in the city. Let $G_d = 748$, $\widetilde{IQ} = 400$, $G_p = 50$, $L_d = 100$, $C_d = 500$, $\Delta C_d = 300$, $R_d = 100$, $IQ = 1000$, $C_s = 400$, $L_s = 300$, $\Delta C_s = 400$, $R_s = 200$, $R_{pH} - C_{pH} = 50$, $R_{pL} - C_{pL} = 80$, $C_p = 100$, $\Delta R_p = 105$, $\Delta R_{pH} = 125$ and $\Delta R_{pL} = 90$. These parameters are expressed in units of 10,000 RMB per annum. Additionally, we set $\alpha = 0.5$, $\beta = 2$, $\lambda = 0.5$, $\zeta = 0.9$.

The influence of initial willingness on evolutionary outcomes

Initial willingness refers specifically to the initial probability that each stakeholder will choose to participate in value co-creation at the beginning of the game. It is an early-stage, probabilistic inclination, reflecting only an initial openness to participate before detailed benefits are assessed. Figure 5(a)-(c) simulate the impact of changes in the initial willingness of the digital technology company, social organization, and elderly care service provider on ESS. Figure 5(d) simulates the effect of simultaneous changes in the initial intentions of all three parties on ESS. The figures reveal that when the parameters satisfy only condition 8, the system evolves towards a stable equilibrium point $(1, 1, 1)$, regardless of the initial willingness of the three parties to participate. However, the initial intentions influence the convergence speed. Specifically:

(1) A comparison of Fig. 5(a)-(c) indicates that the initial intention of the social organization, acting as the platform operator, has the most significant impact on the system's evolution speed. When its willingness to participate is low, the additional costs for the digital technology company, as the platform developer and maintainer, to engage in value co-creation are high, leading to an evolution towards non-participation. In this case, the elderly care service provider lacks the incentive to increase its participation, resulting in a slower convergence towards ESS $(1, 1, 1)$. As the willingness of the social organization to participate increases, the participation intentions of the digital technology company and elderly care service provider also rise, accelerating the system's evolution towards ESS $(1, 1, 1)$.

(2) Figure 5(c) shows that an increase in the initial intention of the elderly care service provider can slow down the convergence speed of the social organization. This may be because the stronger the intention of the service provider to offer high-quality services, the weaker the motivation for the social organization to enforce strict supervision, resulting in slower evolution towards active participation.

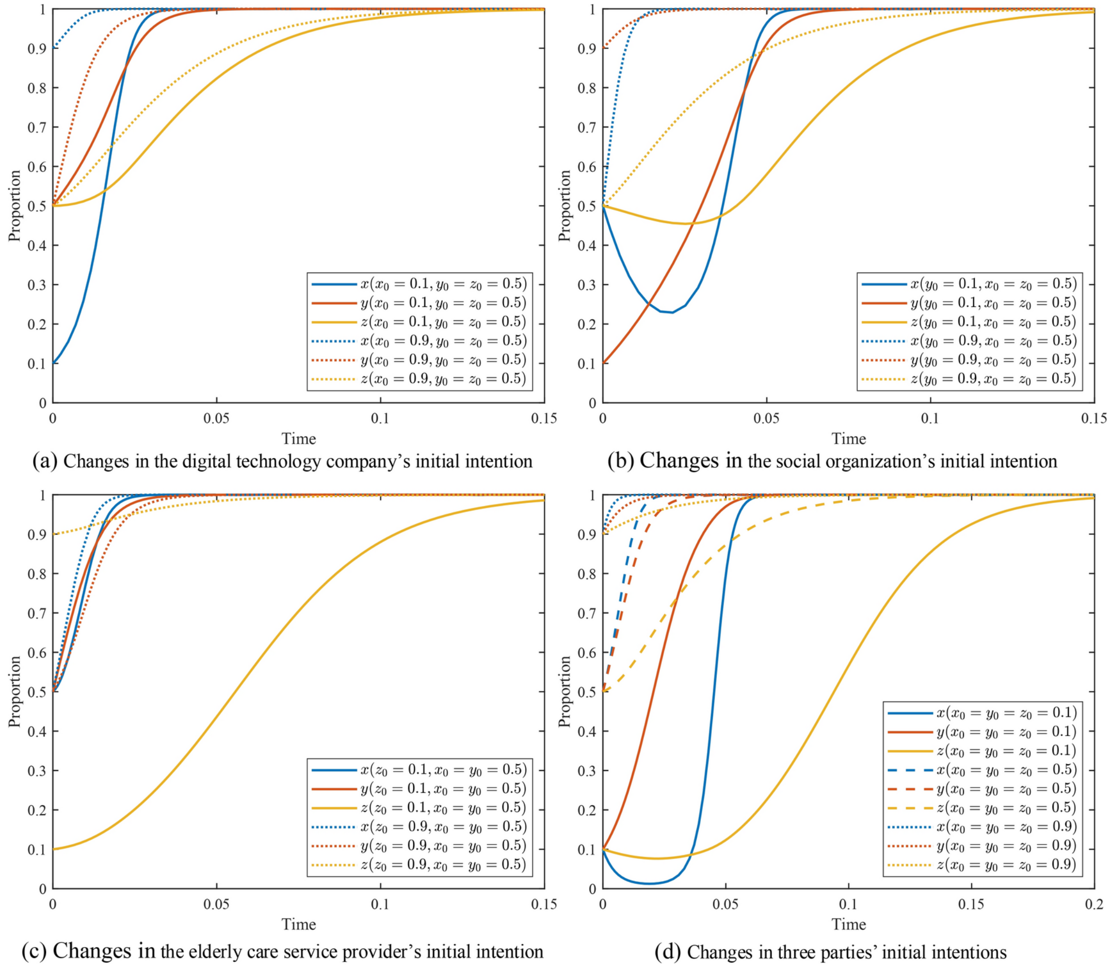
(3) Figure 5(d) indicates that when the initial intentions of all three parties to engage in value co-creation increase simultaneously, the system's convergence speed to the equilibrium point also increases, facilitating the quicker establishment of the platform favored by the elderly. Therefore, when guiding the development of a sustainable elderly care service platform, the government should aim to simultaneously enhance the participation awareness of all three parties, particularly that of the social organization.

The influence of key factors on evolutionary outcomes

Figure 6 analyzes the impact of sales volume on the system's evolutionary outcomes. The figure shows that when the sales volume is too low for the IESP's commission income to cover the additional costs for value co-creation, the digital technology company lacks the motivation to participate. Even with potential reputational losses, it opts out of the ongoing maintenance and upgrade processes of IESP. The social organization and elderly care service provider, in turn, oscillate between participation and non-participation, failing to reach a stable state. Due to low sales volume leading to reduced commission income and the digital technology company's non-participation strategy, the social organization also reduces its willingness to participate, relaxing its supervision over the service provider. As a result, even if the service provider offers high-quality services, it is unable to receive fair ratings due to the passive operation of the social organization, losing opportunities for government subsidies and excess profits from the platform, gradually evolving towards providing lower-quality services.

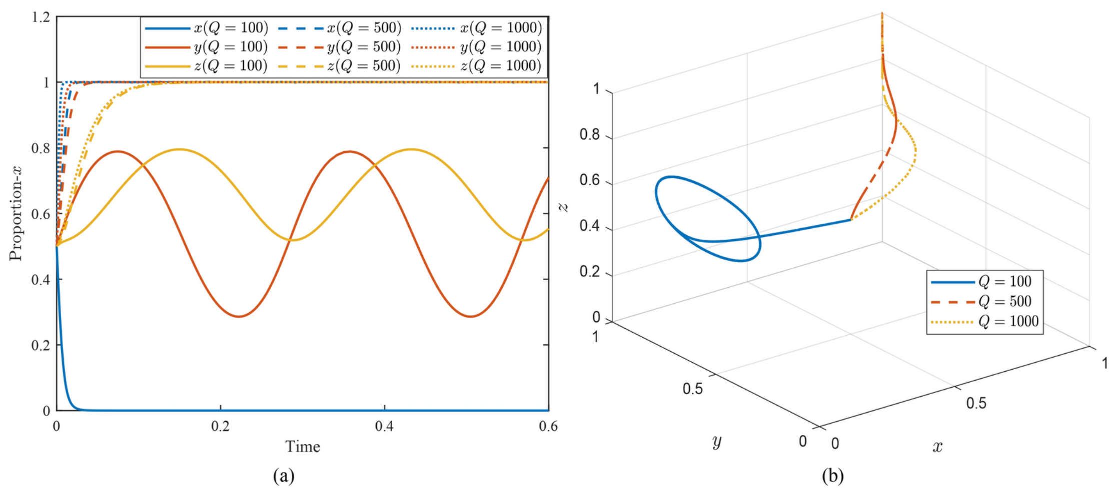
As the service quality on IESP declines, the number of elderly users decreases, and complaints about the platform increase, leading to greater reputational damage for the social organization and lower operational revenues. This, in turn, drives the social organization towards stricter regulation and active participation. The shift in the operational strategy of the social organization enhances the service provider's willingness to participate. Over time, the high participation intention of the service provider again leads to a relaxed operational attitude from the social organization, causing both parties to fall into a continuous cycle of "passive operation—low quality—active operation—high quality—passive operation," preventing the system from reaching a stable equilibrium.

When sales volume increases to the point where the IESP's commission income exceeds the stakeholders' additional costs of value co-creation, the system evolves toward an equilibrium strategy point, with higher sales volume accelerating this evolution. These findings provide managerial insights for the government in guiding the development of a sustainable elderly care service platform. Specifically, user engagement determines the returns



(a) Changes in the digital technology company's initial intention
(b) Changes in the social organization's initial intention
(c) Changes in the elderly care service provider's initial intention
(d) Changes in three parties' initial intentions

Fig. 5. Impact of initial intentions on evolutionary outcomes.



(a)
(b)

Fig. 6. Impact of sales volume on evolutionary outcomes.

that suppliers can earn during the development and operation of IESP. By maximizing service sales volume on IESP and ensuring suppliers earning reasonable profit during its development and operation, suppliers can be incentivized to actively participate in value co-creation.

Figure 7 analyzes the impact of the reputation gains and losses of the digital technology company and the social organization on evolutionary outcomes. As observed in Figs. 7(a) and 7(b), when the additional gains from value co-creation for the digital technology company exceed the additional costs, changes in its reputation gains and losses do not affect the evolutionary outcome but do influence the speed of evolution. The greater the reputation gains and losses, the more decisively the digital technology company adopts the participation strategy, accelerating the system's evolution towards the ESS $(1, 1, 1)$.

Figures 7(c) and 7(d) indicate that, although the additional gains from value co-creation for the social organization also exceed the additional costs in the parameter settings, reputation gains and losses still impact the evolutionary outcome. As a nonprofit entity, the social organization serves as a vital link between the government and the public, with government funding and policy support playing a crucial role in its operations. Therefore, the government's emphasis on the reputation (evaluation rating) of the social organization has a decisive influence on the organization's strategic behavior. When the government does not allocate resources based on the organization's reputation—i.e., when reputation gains and losses are set to zero—the social organization opts out of value co-creation. This is especially true when reputation losses are zero, leading the social organization to rapidly evolve towards non-participation. Consequently, both the digital technology company and the service provider choose non-participation strategies, which is detrimental to the sustainable development of the elderly care service platform.

These findings suggest that the government should enhance its evaluation of the social organization and consider it a key criterion for qualifying for related government incentives and favorable policies.

Figure 8 simulates the impact of changes in government subsidies for a high-quality elderly care service provider on the evolutionary outcomes. The results indicate that under the condition of active participation by the social organization in value co-creation, higher subsidies for the digital transformation of a high-quality service provider leads to faster evolution towards active participation. When the government does not provide additional subsidies to the high-quality service provider, the provider, due to the higher additional costs, ultimately opts out of value co-creation. Therefore, the government can incentivize the service provider to improve service quality by offering additional digital transformation subsidies as rewards for meeting high-quality standards.

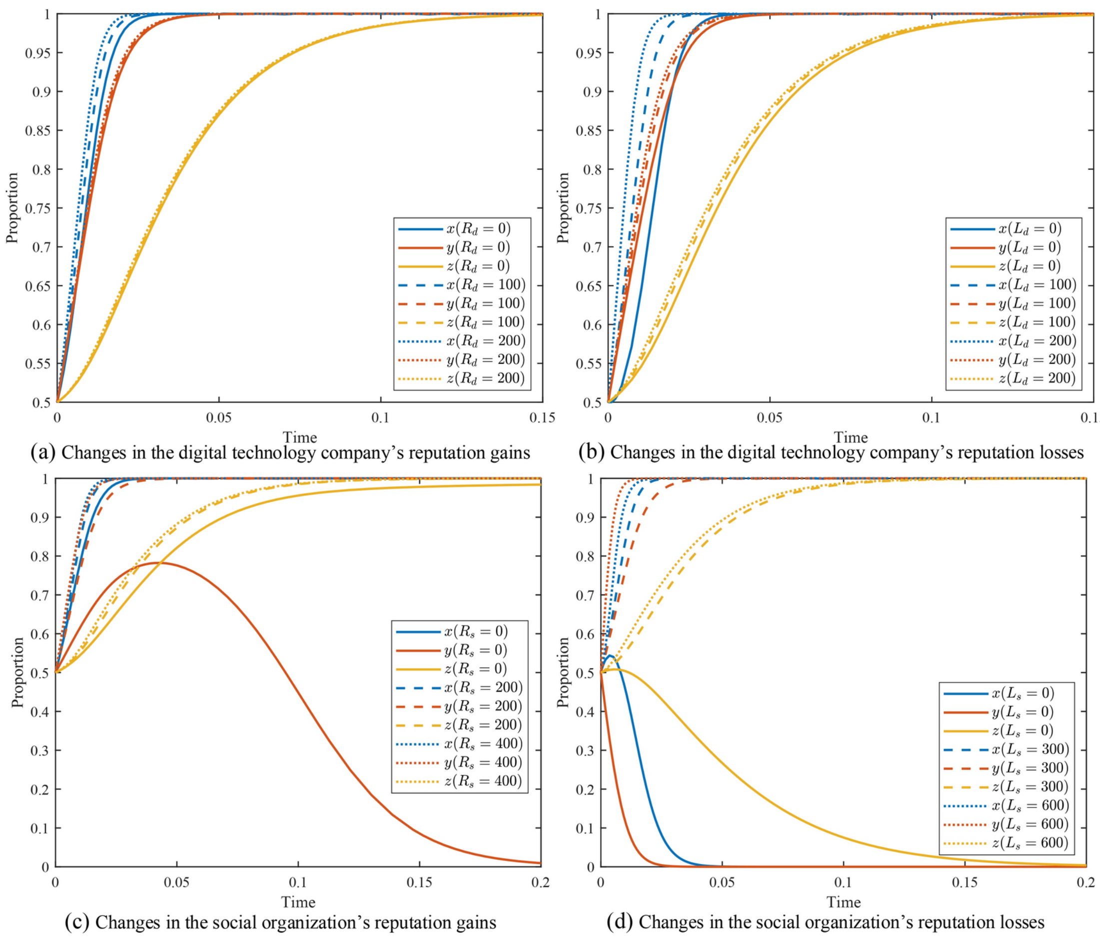


Fig. 7. Impact of reputation gains and losses on evolutionary outcomes.

Conclusions and discussion
Conclusions
As the trend of population aging intensifies, the traditional elderly care service model increasingly struggles to meet the diverse and personalized needs of the elderly. IESP can drive service innovation through data analytics and optimize service supply structure, thereby providing more precise and accessible elderly care services. However, because the platform is designed for a demographic that generally has low technological adaptability and limited physical mobility, its construction, promotion, and operation entail significant costs. These challenges cannot be effectively addressed by market forces alone and require the government to guide the collaboration of multiple stakeholders, including digital technology companies, social organizations, and elderly care service providers. This paper builds an evolutionary game model based on value co-creation theory to explore the factors influencing the behavioral strategies of these stakeholders, offering managerial recommendations for the sustainable development of IESP.

We find that whether the long-term evolution of behavior strategies among various actors trends towards active engagement in value co-creation is primarily influenced by factors such as sales volume, commission income, participation costs, reputation gains, reputation losses, and government subsidies. Platform revenue is associated with user engagement. Only when the service provider connected to the platform deliver high-quality services can elderly users have a positive experience, which enhances their trust in the platform and subsequently increases transaction volume. Participation costs mainly include the expenses for the digital technology company to collect and process data, the costs for the social organization to actively manage and strictly regulate, and the costs for the elderly care service provider to improve service quality and implement digital transformation. Reputation gains and losses not only dictate the position and interaction of the digital company and social organization with the government but also determine their competitiveness in the market, thereby exerting a significant influence on their behavioral strategies. Government subsidies, particularly those supporting the digital transformation of high-quality elderly care providers, can effectively encourage service providers to enhance service quality and increase their willingness to participate in value co-creation. Additionally, the initial willingness of each stakeholder to participate influences the speed of system evolution. The higher the initial willingness, the faster the system evolves towards a scenario where all actors adopt participation strategies.

Management implications
Based on the above findings, we offer the following recommendations for the government to guide the sustainable development of IESP:

1. The government should consider the interests of all parties by allowing the digital technology company and social organization to reasonably earn profits during the development and operation of the platform. These profits can cover their operational costs and provide opportunities for reinvestment, further motivating their participation in the value co-creation ecosystem. By ensuring the economic sustainability of these stakeholders, the government can foster the establishment of a more dynamic and innovation-driven IESP.
2. The government can mobilize grassroots efforts through offline promotional activities to address the limitations elderly individuals face in accessing information. This initiative will help bridge the digital divide, increase the number of active users on IESP, achieve economies of scale, and encourage stakeholders to actively engage in value co-creation.
3. While ensuring data privacy and security, the government should consider opening some databases, establishing data-sharing platforms, and setting unified data standards. This will effectively break down data silos,

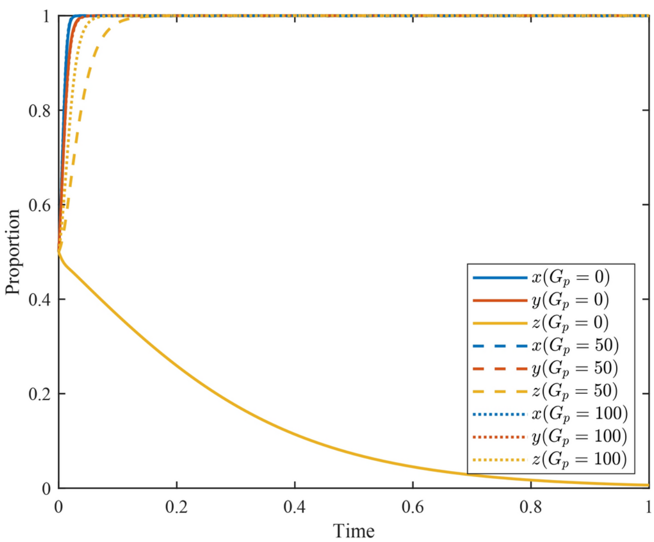


Fig. 8. Impact of government subsidies on evolutionary outcomes.

reduce the cost for the digital technology company to acquire data, and thus enhance its willingness and enthusiasm to participate.

4. The government should strengthen reputation management for the digital company and social organization. Companies actively involved in value co-creation should receive preferential consideration in future collaborations. Conversely, companies that do not cooperate with maintenance after project acceptance should face reduced future collaboration opportunities. Additionally, for the social organization, the government should enhance tiered evaluations and use these assessments as a key criterion for qualifying for relevant incentives and policies.
5. Beyond improving the payment capacity of elderly individuals, the government can establish standardized service provider rating criteria to differentiate service quality. By offering preferential policies and financial subsidies to high-quality service providers, the government can widen the income gap between high and low-quality providers, thus encouraging service providers to enhance service quality. For example, the Shanghai municipal government's "reward-based subsidies" policy could serve as a model.

While this paper uses the case of IESP in Shanghai as a starting point, its core research question focuses on the development and operation of platforms that provide quasi-public goods. Therefore, the contributions of this study extend beyond Shanghai and the elderly care sector; they are relevant to the construction of any digital platforms with long investment return cycles that are not favored by private investment but serve the public interest.

For instance, China's smart healthcare platform, "Health Cloud," similarly requires government support, with digital technology companies (such as Ali Health) providing technical assistance, social organizations handling health education and platform promotion, and healthcare providers delivering the necessary medical services. Additionally, comparable health or elderly care service platforms in other aging countries exhibit similar needs and operational models, highlighting the broader applicability of our findings.

Research limitations and further directions
Our study has certain limitations, such as primarily considering the supply-side perspective and incorporating elderly consumer feedback only as relevant parameters in the model, without accounting for specific decision-making behaviors. In future research, we will focus on integrating elderly consumers' behavior to better refine our considerations for the sustainable development of IESP.

Data availability
The data that support the findings of this study are available from the corresponding author, Qian Guo, upon reasonable request.

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Author contributions

Y.M.: formal analysis, investigation, methodology, writing—review and editing. Y.S.: formal analysis, investigation and editing. Q.G.: formal analysis, funding acquisition, investigation, software and editing. X.W.: formal analysis and editing. All authors contributed to the article and approved the submitted version.

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Declarations

Competing interests
The authors declare no competing interests.

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