

## Article

# Data Element Sharing in Convergence Media Ecology Based on Evolutionary Game

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**Abstract:** As a new factor of production, data element has profoundly changed our mode of production, lifestyle and social governance style. The sharing of a data element in the convergence media ecology can greatly improve the circulation of a data element and enhance the value of a data element; however, it may face problems such as insufficient sharing willingness, incomplete sharing circulation mechanism and inadequate implementation of the incentive mechanism. To solve these problems, this paper introduced the evolutionary game theory in the convergence media ecology and established the data-sharing model according to the characteristics of nodes. We analyzed the ecological node evolution path, evolutionary stable strategy and the corresponding state conditions in the model. Furthermore, we carried out the sampling experiment simulation, which verified the effectiveness of the research content in this paper. At the end of the article, we summarize and give some key factors to increase the willingness to participate in sharing in convergence media ecology. This paper enriched the research field of data element sharing in convergence media and explored the willingness and tendency of the participants. The research results can provide targeted suggestions for promoting the sharing of data elements in convergence media ecology.

**Keywords:** convergence media ecology; data element; evolutionary game; evolutionary stable strategy; replication dynamic equation



**Citation:** Hu, H.; Wang, Y.; Song, G.; Fan, W.; Liu, C. Data Element Sharing in Convergence Media Ecology Based on Evolutionary Game. *Appl. Sci.* **2023**, *13*, 10089. <https://doi.org/10.3390/app131810089>

Academic Editors: Dickson K.W. Chiu and Kevin K.W. Ho

Received: 4 August 2023

Revised: 4 September 2023

Accepted: 5 September 2023

Published: 7 September 2023



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## 1. Introduction

In recent years, with the development of science and technology, the media industry has achieved rapid development and has experienced three development stages, from traditional media to new media and then to convergence media [1,2]. Traditional media mainly comprises radio, television and newspapers, while new media is predominantly represented by mobile and Internet-based platforms. Convergence media, on the other hand, emphasizes the holistic evolution of media formats. Convergence media is a new media form that makes full use of media carriers and integrates different media such as radio, television, newspaper, mobile phone and Internet with both common ground and complementarity in terms of manpower, content, communication and governance [3]. As new media continues to develop, it brings about significant transformations in media patterns and modes of communication. The reorganization of various media forms and resources to form a joint force has become the main form of expression of media, which is also the main feature of the stage of convergence media [4]. In the convergence media ecology, different media organizations can establish connections by setting up unified standard application program interface, and at the same time, they can set up unified standard data formats and media resource libraries to realize the circulation of data elements so as to adapt to the impact of technological iteration. At present, the media industry is in a critical stage of the development of convergence media. The recombination of different media forms and resources and the application of artificial intelligence, big data, blockchain

and other technologies have promoted the intelligent matching of information and user needs and improved the operation and maintenance efficiency of convergence media [5–7]. However, the development of convergence media still faces a series of problems and challenges, including information traceability, technology and media integration, data security and user privacy, and data circulation efficiency [8].

Data elements refer to data resources that participate in social production and management activities, bring economic benefits to users or owners, and are recorded electronically [9]. As a new factor of production, data have profoundly changed our mode of production, lifestyle and social governance. With the continuous innovation of data collection, governance, application, safety and other technologies and the rapid development of the industry, the current data element market construction has achieved remarkable results, the market environment has constantly improved, and the quality of data elements has been greatly improved [10]. With the advent of the era of big data, media have paid unprecedented attention to the integration and accumulation of big data resources [11]. Building a new platform of “media data” and seizing a new highland of “data media” has become the direction of many media organizations [12].

The goal of the research on the data element market is the efficient, orderly and free circulation of data elements among various market entities, which can be explained by the circulation mode of the data element, the circulation technology of the data element and the circulation system of data element [13,14]. According to the different circulation of data and interests between subjects, its circulation mode can be divided into three types: opening, sharing and trading [15]. Data opening refers to the form of one-way data circulation in which the provider provides data free of charge and the demander obtains data free of charge without the participation of monetary media; data sharing refers to the form of two-way data circulation in which both supply and demand parties provide data to each other, roles can be changed, and there is no monetary medium involved; data trading refers to the form of one-way data circulation in which the provider provides data with compensation and the demander pays the acquisition fee, mainly using currency as the medium of exchange [16]. Data element circulation technology is mainly a technology to ensure the smooth circulation of data elements, such as data collection, data registration, data confirmation, data recommendation, data transmission, data storage, privacy protection, etc. [17]. Data element circulation system mainly includes a data value evaluation system, data ownership system, data use system, etc. [18]. These links have a new impact on the specific behavior of ecological nodes. At the same time, in order to ensure the normal operation of the entire data circulation system, the entire system must be under the regulation of relevant laws and industry standards. Data element circulation model is shown in Figure 1.

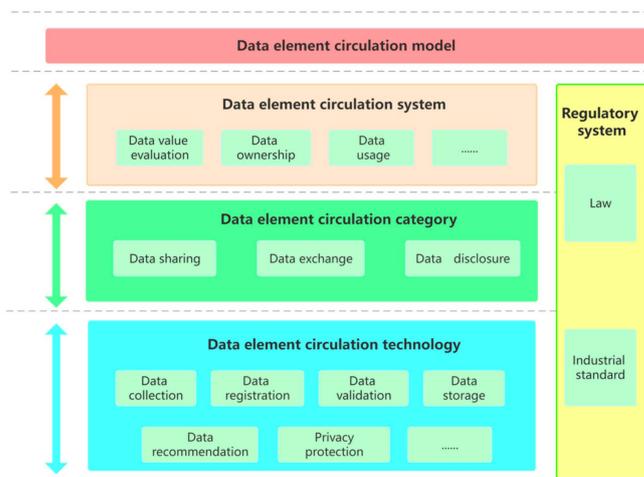


Figure 1. Data element circulation model.

In the convergence media ecology, each node can act as the producer of the data element and can also become the consumer of the data element [19]. Studying the sharing of data elements in the convergence media ecology is an important topic in the healthy development of the convergence media ecology, which can greatly improve the utilization rate of data resources and promote the overall value of data elements in the ecology. According to the special attributes of the media industry, the data element in the convergence media ecology can be mainly divided into the following categories [20–23]:

(1) Content data

Content data are the core data of the convergence media ecology and also an important part of the circulation of data elements in the convergence media ecology. Generally, they can be divided into the following categories according to the data format [24–26]:

- ① Literal data. Literal data are one of the most basic elements in the convergence media, including news, reports, comments, analysis and other text content.
  - ② Image data. Image data refer to non-text media, such as pictures and photos, which can be used to supplement and enrich the text content and improve the reading experience of readers.
  - ③ Audio data. Audio data refer to the media content presented in the form of sound, including music, radio programs, podcasts, etc., which can convey information and emotion through sound.
  - ④ Video data. Video data refer to the media content presented in the form of video, including news reports, movies, documentaries, etc., which can be conveyed through multiple dimensions, such as vision and sound.
- (2) Interactive data: These are the data describing the interaction between the content and users, including users' comments, likes and sharing of the content. Interactive data can help parties within the ecosystem to understand users' interests and feedback on content and improve the quality of content within the ecosystem.
- (3) Content copyright data: These include copyright ownership and authorization of original content, which can be recorded and stored safely using blockchain and other technologies so as to realize the protection and maintenance of content copyright data.
- (4) Value assessment data: These describe the value of content and user value, which can help parties within the ecosystem assess the value of content and the value of users. Value evaluation data can provide a basis for resource allocation and content recommendation within the ecology.
- (5) Advertising data: These include the display amount of advertising, clicks, conversion amount and other data, which can be safely recorded and stored so as to realize the credibility and transparency of advertising data [27].
- (6) User data: These describe the user information, including the user's basic information, account information, behavioral data, etc. User data can help parties in the ecosystem understand user needs and behaviors and better-targeted services [28].
- (7) Authentication data: These describe the content authentication information and the user identity authentication information. Authentication data can help parties in the ecosystem to confirm the authenticity of the content and the identity of users and improve the credibility of information within the ecology [29].
- (8) Transaction data: These include payment, transfer, points exchange and other data between users, which can be safely recorded and stored so as to realize the security and traceability of transaction data.
- (9) Circulation data: These describe the circulation of digital assets, including digital asset transaction records, distribution records, etc. Circulation data can help parties within the ecosystem assess the value of the content and better manage digital assets.

With the transformation of the media industry to digital, much data are generated and collected, and strengthening the circulation of data elements has very important significance. We must pay attention to privacy, copyright and other related issues in the process of circulation, and must be in accordance with national laws and ecological

requirements. The sharing of data elements in convergence media ecology can greatly improve the circulation of data elements and enhance the value of data in ecology. However, the sharing of data elements in ecology may face the following problems [30–32]:

(1) Insufficient willingness to participate in sharing.

The enthusiasm of ecological nodes to participate in the circulation of data elements is not high, and the phenomenon of data islands is serious, resulting in the value of data elements in the convergence media ecology is not fully utilized. Therefore, encouraging nodes to participate in the circulation of data elements has become a key problem facing the ecological development of convergence media.

(2) The circulation mechanism of a data element is incomplete.

The participation of ecological nodes in the circulation process of data elements is not clear, resulting in the chaotic circulation process of data elements. Therefore, the formulation of detailed and clear data element circulation strategies is an important factor for the sustainable development of convergence media ecology.

(3) The implementation of an incentive mechanism is not in place.

The implementation of the incentive mechanism of ecological node circulation data is not in place, which easily leads to damage to the enthusiasm of nodes. Therefore, the accurate and timely implementation of incentive policies is an important guarantee for the sustainable development of convergence media ecology.

(4) Data privacy and security issues. It must be carried out on the premise of complying with national laws and relevant ecological requirements. Blockchain and other technologies can ensure the immutability and security of data, but some sensitive data also need to be encrypted to protect data privacy.

(5) Data quality issues. The quality of data is crucial to the normal operation of the media ecology, so data need to be monitored and reviewed to ensure its quality.

(6) Data standard issues. Data standards may vary for different organizations and individuals, so uniform data standards need to be used to facilitate the flow of data elements.

(7) Data equity issues. Data element sharing may cause disputes over data rights and interests, so it is necessary to clarify the ownership of data and the right to use them to avoid disputes.

In summary, the node willingness, data element ownership, data security risk, data element sharing cost and other issues involved in data element sharing in ecology still restrict the improvement of the level of data element sharing [33].

Evolutionary game theory is a theoretical framework to describe the interaction between biological populations or social groups in competition or cooperation. Evolutionary game theory combines individual behavior with group dynamics, considers the influence of factors such as natural selection and genetic drift on evolution, and can better explain the evolutionary behavior of biological and social systems, which we usually use to describe the interaction between individuals [34,35]. Commonly used concepts in evolutionary game theory include evolutionary stable strategy, replicator dynamics, etc. Evolutionary stable strategy (ESS) is a core concept of evolutionary game theory, and it is a strategy that natural selection tends to maintain; even in the face of all other possible evolutionary strategies, this strategy can still maintain its dominant position [36]. Replicator dynamics is a mathematical model that describes how the proportion of different strategies in a population changes over time, where strategies grow at a rate proportional to their advantage over average fitness, and the replication dynamic equation in an evolutionary game refers to the simple imitation of the dominant strategy by the finite rational group players, which is expressed by dynamic differential equation or differential equation systems [35,37].

In order to solve the problems faced by data element sharing in the convergence media ecology, such as insufficient ecological activity, inadequate implementation of the reward mechanism and imperfect data element circulation mechanism, this paper attempts to

study the introduction of evolutionary game into the ecological node to promote data element sharing according to the characteristics of the nodes in the convergence media ecology, and we established a data element sharing model based on the evolutionary game to provide targeted suggestions for promoting data element sharing in convergence media ecology.

## 2. Related Work

In recent years, there has been a swift and substantial growth within the media industry. With the application of blockchain, artificial intelligence, big data, cloud computing and other technologies in the convergence media ecology, the convergence media ecology has made certain progress in digital copyright protection, content review and content traceability, and the development of the convergence media ecology has continued to mature [38–42]. Hu et al. propose that blockchain-based convergence media leverages blockchain's features to enhance the media industry, and they outline a sustainable convergence media ecology built on blockchain and introduce a consensus mechanism named PoE for this context [43]. Singh et al. introduced a practical method that integrates cloud computing and social media analytics to effectively supervise and manage government policies with public engagement, and their approach proved successful in testing for the implementation of GST by the Indian government, showcasing its utility in efficient policy formulation and execution [44].

With the continuous improvement of the media ecosystem, great changes have taken place in the media industry in terms of content production methods, forms of expression, communication mechanisms, operation and maintenance management [45,46]. Wang states that the proportion of traditional media and new media in the field of news has changed significantly, and in order to achieve sustainable development, media should innovate and optimize their business philosophy and mode of operation, improve the theoretical and practical level of news editing, use modern consciousness to edit news, and achieve their own progress through integration and innovation [47]. Lin et al. explain that media convergence involves processing information from different sources and applying it to various domains, but conventional knowledge graphs struggle with multimedia features due to the introduction of extensive cross-modal information, which diminishes representation learning effectiveness and knowledge graph inference; they introduced a remedy through their Media Convergence and Rule-guided Joint Inference model (MCRJI) [48].

Evolutionary game theory combines game theory analysis with dynamic evolutionary process analysis, and it emphasizes a dynamic equilibrium differing from traditional game theory's focus on static equilibrium [49–51]. Liu et al. developed a tripartite evolutionary game model encompassing the strategies of the service platform, government and consumers, proposing a governance mechanism to counteract the utilization of Big Data Discriminatory Pricing (BDDP) by the service platform and their study concluded with insights into effective service platform governance [52]. Sohrabi et al. introduced an evolutionary game theory approach for materialized view selection in data warehouses, utilizing a multi-view processing plan structure to encapsulate the problem's search space, and empirical assessments demonstrated its effective convergence in large data warehouses and efficient execution time [53]. Xu et al. investigated regulators' and financial institutions' behavioral strategies and game outcomes using four constructed evolutionary game models, unveiling experimental results through numerical simulations of game interactions involving a commercial bank in China [54]. Xiao et al. applied evolutionary game theory to examine the symbiotic and antagonistic dynamics between rumors and anti-rumor efforts, presenting a quantitative model that comprehensively accounts for internal and external factors influencing user behavior during rumor propagation [55]. Zhang et al. integrated prospect theory and mental account theory into an evolutionary game model to analyze how reward and punishment strategies on shared platforms impact quality decision-making, offering valuable insights for enhancing shared manufacturing quality and its role in the manufacturing industry's transformation and development [56].

This paper expounds on the definition and relevant application scenarios of the convergence media ecology and data element and expounds on the main classification of the data element in the convergence media ecology and the main problems faced by data element sharing. Based on the analysis of these problems, this paper attempts to study how to promote the data element sharing of ecological nodes by introducing the evolutionary game into the ecology. According to the characteristics of nodes in the convergence media ecology, this paper studies and designs a data element sharing model based on the evolutionary game; analyzes the evolutionary path, evolutionary stability strategy and corresponding state conditions of the model; and conducts sampling simulation through experiments. The sampling experiment results verify the validity of the research content in this paper. This paper enriches the research field of data element sharing in the convergence media ecology and explores the willingness tendency of all participants in data element sharing; additionally, the research results can provide targeted suggestions for promoting data element sharing in the convergence media ecology.

### 3. Data Element Sharing Model Based on Evolutionary Game

#### 3.1. Node Classification

According to the characteristics of nodes in the convergence media ecology, there are two modes of relationship between nodes in the process of data element sharing based on the evolutionary game:

##### (1) Producer and consumer model

In the producer and consumer model, producers and consumers are clearly distinguished, and each plays a different role. The producers are mainly news media organizations, enterprises, etc., the main function of which is the production of data elements, and the consumers are mainly common users, the main function of which is the use and consumption of data elements [57].

The advantages of this mode are as follows:

- ① Clear role: Producers focus on producing high-quality data elements, while consumers focus on acquiring, screening, sharing and interacting data elements.
- ② Help to maintain data quality: Producers can better ensure data quality and reliability and reduce the risk of false information dissemination.
- ③ Research iteration: The node function in the system is clear, which is more convenient to study the system sharing efficiency so as to promote the system update iteration.

The disadvantages of this model are as follows:

- ① Limiting innovation and engagement: Too much explicit role division may limit the motivation of common users to participate in data element production, reducing content innovation and diversity.
- ② Information asymmetry: There may be information asymmetry between producers and consumers, resulting in some data elements that cannot be effectively spread and shared.

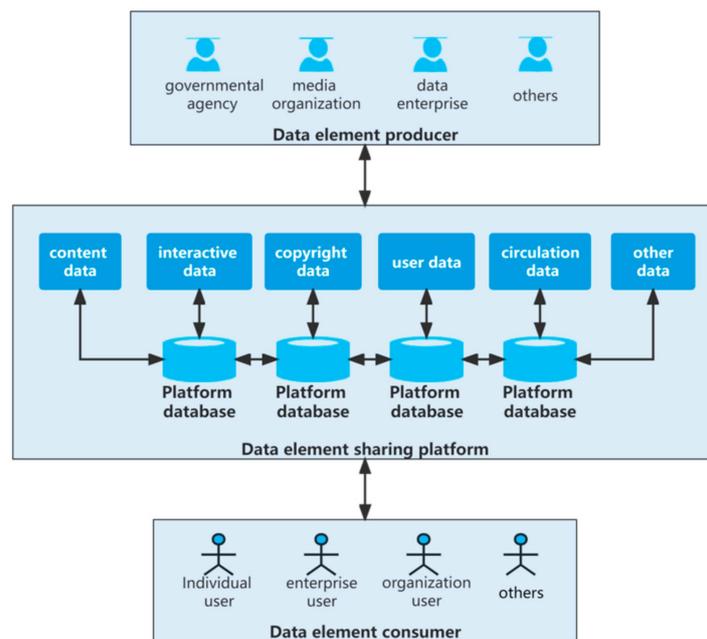
Producer and consumer node pattern is shown in Figure 2.

##### (2) Undifferentiated node pattern

In this model, all participants are seen as differentiated nodes that can both produce and consume data elements.

The advantages of this mode are as follows:

- ① Innovation and diversity: Encourage users to participate in the production of data elements and increase the innovation and diversity of content.
- ② Fluent information flow: Undifferentiated node mode helps to break down the information barriers and realize the wider sharing and dissemination of data elements.

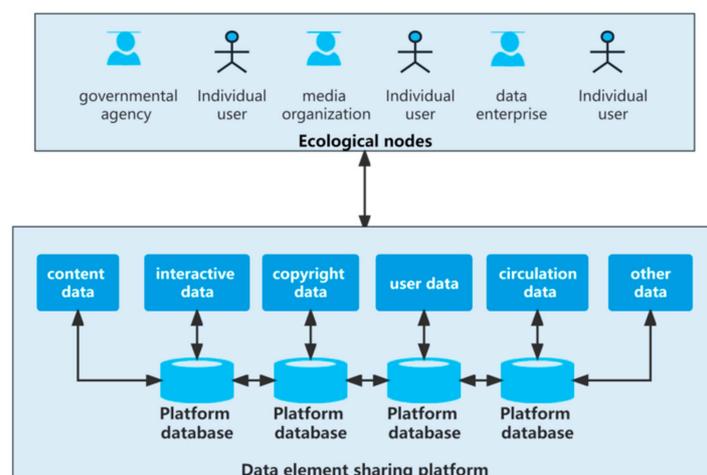


**Figure 2.** Producer and consumer node pattern.

The disadvantages of this model are as follows:

- ① Data quality is difficult to control: the lack of clear producer and consumer roles may make it difficult to guarantee data quality and reliability.
- ② Resource allocation efficiency may be reduced: In the undifferentiated node model, participants may need to distract between production and consumption, potentially reducing the efficiency of resource allocation and utilization.
- ③ Difficult to target research: In the undifferentiated node mode, the functional characteristics of nodes are weakened, and it is difficult to reflect the targeted characteristics of research.

Undifferentiated node pattern is shown in Figure 3.



**Figure 3.** Undifferentiated node pattern.

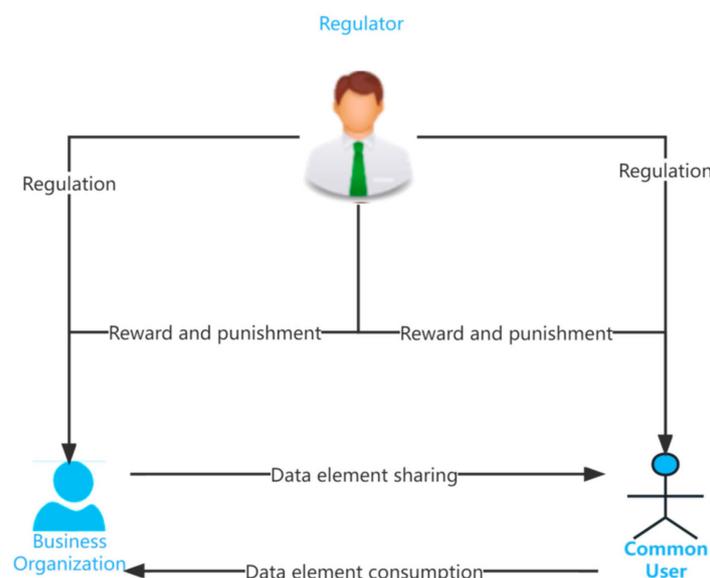
In order to facilitate the study of ecological data elements sharing based on the evolutionary game, analyze the game strategies of different roles in sharing of which the influence on the sharing of data elements, and, at the same time, guarantee the quality of data sharing, this paper adopts producers and consumers model to study the sharing process. In the ecological actual operational process, node can flexibly transform producer

and consumer roles to improve the efficiency of the ecological whole. At the same time, in order to ensure the enthusiasm of nodes to participate in sharing and the quality of sharing data elements, regulator nodes are introduced in the ecology.

In conclusion, we divided nodes into three categories according to the functional positioning of nodes participating in data element sharing:

- (1) Business organization node (*B*). Business organization nodes involved in the convergence media ecological data element sharing mainly as data producers for common users or other institutions to provide raw data and resources, such as articles, pictures, audio, video, statistics, etc., these nodes usually adjust strategy according to the incentive mechanism to share data element, in order to obtain relatively higher income.
- (2) Common user node (*U*). Common user nodes participate in data element sharing in the convergence media ecology mainly as consumers of data elements participate in the acquisition, use and quality feedback of data elements.
- (3) Regulator node (*R*). The participation of regulator nodes in data element sharing in the convergence media ecology is mainly responsible for the regulation of the quality of data element sharing. It urges business organization nodes to actively participate in the production and sharing of high-quality data elements and common user nodes to participate in data element consumption and quality feedback. The regulator nodes distribute rewards according to the behavior of the user nodes and punish the node violations.

Data element sharing node relationship is shown in Figure 4.



**Figure 4.** Data element sharing node relationship.

In the data element sharing based on the evolutionary game, the user nodes can cooperate and compete with each other to realize the data element sharing. Evolutionary game theory can help us to analyze the strategy selection and evolution between nodes so as to design appropriate incentive mechanisms to promote the healthy development of the whole ecosystem.

### 3.2. Basic Assumption

In order to construct a three-party game model in the convergence media ecology and analyze the game strategy of all parties, the stability of equilibrium points and the influence of each factor on the game results, the following assumptions are made by comprehensively considering the node characteristics in the ecology:

- (1) Node-wise finite rationality. The business organization node, common user node and regulator node are all limited and rational subjects.
- (2) Policy space ( $S$ ). All three parties of the evolutionary game are users in the convergence media ecology. The policy space of the business organization node  $S_B = \{\text{positive data element sharing, negative data element sharing}\}$ , the probability of the business organization node to positively participate in data element sharing is  $x$ ; the policy space of the common user node  $S_U = \{\text{participate in data element sharing, not participate in data element sharing}\}$ , the probability of the common user node participating in data element sharing is  $y$ ; the policy space of the regulator node  $S_R = \{\text{regulate data element sharing, not regulate data element sharing}\}$ , and the probability of the regulator node participating in data element sharing regulation is  $z$ . In order to facilitate the research, this paper regards the business organization node, common user node and regulator node as a whole, respectively.
- (3) Participation cost ( $G$ ). In the process of data element sharing, nodes need to pay a certain cost, which includes but is not limited to data, time cost of content production, labor cost, economic cost of data abuse, etc. In this model, the positive sharing cost of business organization nodes is denoted as  $G_{11}$ , and negative sharing costs are denoted as  $G_{12}$ ; the cost of common user nodes participating in sharing is denoted as  $G_2$ , and the cost of not participating in sharing is 0; and the cost of regulation carried out by the regulator node is denoted as  $G_3$ , and the cost of not regulating is 0.
- (4) Benefits of participation in sharing ( $E$ ). When the business organization node chooses to positively share data elements and the common user node chooses to participate in data element sharing, the node will receive sharing revenue. The business node is mainly generated by sharing its own data element with other nodes, mainly determined by the value of the shared data element and unit price; the common user node is mainly generated by the revenue generated by consumption after obtaining the data element, which depends on the value of shared data element, the value transformation ability of data element and the sharing revenue coefficient of data element. In this paper model,  $E_{11}$ ,  $E_{12}$  represent the revenue of positively participating in sharing and the revenue of negatively participating in sharing of business organization nodes ( $E_{11} > E_{12}$ ), and  $E_2$  represents the revenue of common user nodes participating in sharing. When the business organization node is positively sharing, and the common user node is participating in sharing, it will promote the harmonious development of ecology, and the two parties will have collaborative benefits  $H(H > 0)$ .
- (5) Dynamic incentive benefits ( $I$ ). In the media ecology, in order to encourage nodes to participate in data sharing, dynamic incentive rewards are given to participating nodes, and the size of incentive value is positively correlated with node credit  $C$  and node sharing participation  $P$ . In this model  $I_1$  and  $I_2$  are the dynamic incentive benefits of business organization nodes positively participating in data element sharing and common user nodes participating in data element sharing.
- (6) Regulatory benefits ( $R$ ). The basic revenue generated by the regulator node choosing to regulate the ecological node is  $R$ . The additional revenue coefficient obtained from the successful urging business organization nodes to positively participate in sharing is  $\alpha(\alpha \in [0, 1])$ , and the additional revenue coefficient obtained from the successful urging common user nodes to participate in sharing is  $\beta(\beta \in [0, 1])$ .
- (7) Punishment mechanism. When the business organization nodes choose negative data element sharing, they will be punished  $F_1$  accordingly. When the regulator nodes choose not to regulate, there is a corresponding penalty  $F_3$ .

Parameter setting and symbol description are shown in Table 1.

**Table 1.** Parameter setting and symbol description.

Symbol	Parameter Description
$E_{11}$	The revenue of business organization nodes positively participate in data element sharing.
$E_{12}$	The revenue of business organization nodes negatively participate in data element sharing.
$G_{11}$	The cost of business organization nodes positively participate in data element sharing.
$G_{12}$	The cost of business organization nodes negatively participate in data element sharing.
$I_1$	The dynamic incentive revenue of business organization nodes positively participate in data element sharing.
$F_1$	The system punishment for business organization nodes negatively participate in data element sharing.
$E_2$	The revenue of common user nodes' participation in data element sharing.
$G_2$	The cost of common user nodes' participation in data element sharing.
$I_2$	The system dynamic incentive revenue of common user nodes participating in data element sharing.
$R$	The revenue of regulator nodes participating in data element sharing regulation.
$G_3$	The cost of regulator nodes participating in the regulation of data element sharing.
$\alpha$	The additional revenue coefficient obtained from the successful urging business organization nodes to positively participate in sharing.
$\beta$	The additional revenue coefficient obtained from the successful urging of common user nodes to participate in sharing.
$F_3$	The system punishment of regulator nodes does not participate in data element sharing regulation.
$H$	The revenue received by the parties participating in the sharing. When the business organization node actively participates in sharing and the common user node participates in sharing.
$x$	The probability of the business organization nodes to positively participate in data element sharing.
$y$	The probability of the common user nodes to participate in data element sharing.
$z$	The probability of regulator nodes participating in data element sharing regulation.

3.3. Model Construction and Evolutionary Path Analysis

Let the payoff function of the participating data element sharing nodes in the system be  $S$ , then the payoff matrix of the data element sharing is shown in the following Table 2.

**Table 2.** Data element sharing game benefit matrix.

The Revenue Function (S)		Regulator (R)	Business Organization (B)	
			Positively Share (x)	Negatively Share (1 - x)
Common User (U)	Share (y)	Regulate (z)	B: $E_{11} + I_1 + H - G_{11}$ U: $E_2 + I_2 + H - G_2$ R: $R * (1 + \alpha + \beta) - G_3$	B: $E_{12} - G_{12} - F_1$ U: $E_2 + I_2 - G_2$ R: $R * (1 + \beta) - G_3$
		Do Not Regulate (1 - z)	B: $E_{11} + I_1 + H - G_{11}$ U: $E_2 + I_2 + H - G_2$ R: $-F_3$	B: $E_{12} - G_{12} - F_1$ U: $E_2 + I_2 - G_2$ R: $-F_3$
	Do Not share (1 - y)	Regulate (z)	B: $I_1 - G_{11}$ U: 0 R: $R * (1 + \alpha) - G_3$	B: $-G_{12} - F_1$ U: 0 R: $R - G_3$
		Do Not Regulate (1 - z)	B: $I_1 - G_{11}$ U: 0 R: $-F_3$	B: $-G_{12} - F_1$ U: 0 R: $-F_3$

- (1) Expected revenue function and replication dynamic equation of business organization node.

The expected revenue of the “positive data element sharing” strategy of the business organization node is defined as  $P_1$ , the expected revenue of the “negative data element sharing” strategy is  $P_2$ , the average expected revenue is  $\bar{P}$ , and the calculation formula is:

$$P_1 = y * z * (E_{11} + I_1 + H - G_{11}) + y * (1 - z) * (E_{11} + I_1 + H - G_{11}) + (1 - y) * z * (I_1 - G_{11}) + (1 - y) * (1 - z) * (I_1 - G_{11}) = y * H + y * E_{11} + I_1 - G_{11} \tag{1}$$

$$P_2 = y * z * (E_{12} - G_{12} - F_1) + y * (1 - z) * (E_{12} - G_{12} - F_1) + (1 - y) * z * (-G_{12} - F_1) + (1 - y) * (1 - z) * (-G_{12} - F_1) = y * E_{12} - G_{12} - F_1 \tag{2}$$

$$\bar{P} = x * P_1 + (1 - x) * P_2 = x * [y * H + y * E_{11} + I_1 - G_{11}] + (1 - x) * [y * E_{12} - G_{12} - F_1] \tag{3}$$

The replication dynamic equation of the game strategy of the business organization node is:

$$F(x) = \frac{dx}{dt} = x * (P_1 - \bar{P}) = x * (1 - x)(P_1 - P_2) = x * (1 - x) * (y * H + y * E_{11} - y * E_{12} + I_1 + F_1 + G_{12} - G_{11}) \tag{4}$$

The first derivative of the replication dynamic equation  $F(x)$  of the business organization node is as follows:

$$F'(x) = (1 - 2x) * (y * H + y * E_{11} - y * E_{12} + I_1 + F_1 + G_{12} - G_{11}) \tag{5}$$

According to the evolutionary game theory, the equilibrium point of the evolutionary game is obtained when the result of the replication dynamic equation is 0, and the first derivative is less than 0 [58], and it can be expressed as follows:  $F(x) = 0$  and  $\frac{dF(x)}{dx} < 0$ .

Let  $L(y) = y * H + y * E_{11} - y * E_{12} + I_1 + F_1 + G_{12} - G_{11}$ , we can obtain:

$$\frac{dL(y)}{dy} = H + E_{11} - E_{12} \tag{6}$$

Because  $E_{11} > E_{12}$  and  $H > 0$ , so  $\frac{dL(y)}{dy} > 0$ , then  $L(y)$  is an increasing function about  $y$ . Let  $L(y) = 0$ , we can obtain:

$$y^* = \frac{G_{11} - G_{12} - I_1 - F_1}{H + E_{11} - E_{12}} \tag{7}$$

Let  $F(x) = 0$ , we can obtain:  $x = 0$  or  $x = 1$  or  $y = \frac{G_{11} - G_{12} - I_1 - F_1}{H + E_{11} - E_{12}}$ . Let  $y^* = \frac{G_{11} - G_{12} - I_1 - F_1}{H + E_{11} - E_{12}}$ .

- ① When  $y = y^*$ , for any  $x(0 \leq x \leq 1)$ , we can obtain  $F(x) = 0$ . It shows that all the strategies that meet the constraints of the business organization nodes are stable states, and the positive sharing probability  $x$  of the business organization nodes will not change with time.
- ② When  $y \neq y^*$ , we can obtain  $x = 0$  and  $x = 1$ , which are two evolutionary stable strategies for the business organization nodes. At this point, we need to discuss the distribution of  $F'(x)$  values:
  - a. When  $\frac{G_{11} - G_{12} - I_1 - F_1}{H + E_{11} - E_{12}} > 1$ , because  $0 \leq y \leq 1$ , so  $y < y^*$ . According to the monotonicity of the function  $L(y)$ , we obtain  $L(y) < 0$ , then we can obtain  $F'(0) < 0$  and  $F'(1) > 0$ , so  $x = 0$  is an evolutionary stable point, which indicates that the increased revenue of the business organization node is less than the increased cost of the active sharing, and the negative sharing of the business organization node is the evolutionary stability strategy.
  - b. When  $\frac{G_{11} - G_{12} - I_1 - F_1}{H + E_{11} - E_{12}} < 0$ , because  $0 \leq y \leq 1$ , so  $y > y^*$ . According to the monotonicity of the function  $L(y)$ , we obtain  $L(y) > 0$ , and then we can obtain  $F'(0) > 0$  and  $F'(1) < 0$ , so  $x = 1$  is an evolutionary stable point, indicating that the increased revenue of the business organization nodes is more than the increased cost of the

active sharing, and the positive sharing of the business organization nodes is an evolutionary stability strategy.

- c. When  $0 < \frac{G_{11}-G_{12}-I_1-F_1}{H+E_{11}-E_{12}} < 1$ , it was also necessary to discuss the size relationship between  $y$  and  $y^*$ :

When  $y < y^*$ , we can obtain  $F'(0) < 0$  and  $F'(1) > 0$ , so  $x = 0$  is an evolutionary stable point.

When  $y > y^*$ , we can obtain  $F'(0) > 0$  and  $F'(1) < 0$ , so  $x = 1$  is an evolutionary stable point.

Phase diagram of business organization node’s strategy evolution is shown in Figure 5.

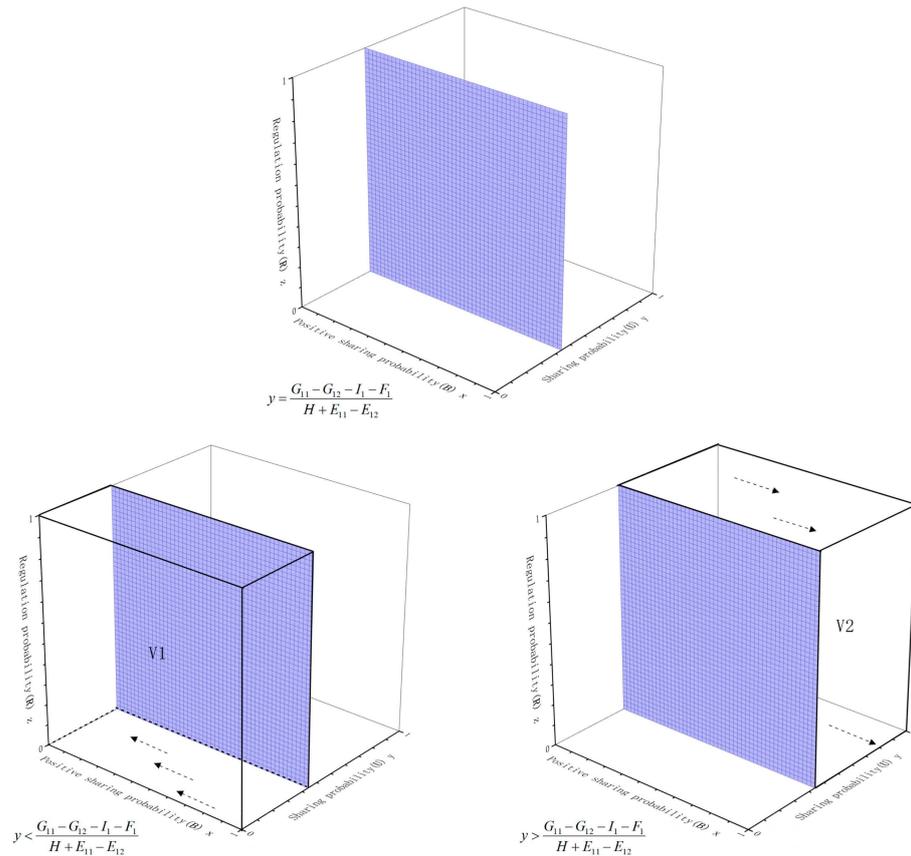


Figure 5. Phase diagram of business organization node’s strategy evolution.

According to the figure above, the probability of selecting negative data element sharing is volume  $V_1$ , and the probability of selecting positive data element sharing is volume  $V_2$ . The projection interval of the surface  $y = \frac{G_{11}-G_{12}-I_1-F_1}{H+E_{11}-E_{12}}$  onto the  $xoz$  plane is  $0 \leq x \leq 1, 0 \leq z \leq 1$ . So the volume  $V_1$  calculation formula is as follows:

$$V_1 = \int_0^1 \int_0^1 \frac{G_{11} - G_{12} - I_1 - F_1}{H + E_{11} - E_{12}} dz dx = \frac{G_{11} - G_{12} - I_1 - F_1}{H + E_{11} - E_{12}} \tag{8}$$

$$V_2 = 1 - V_1 = 1 + \frac{G_{12} + I_1 + F_1 - G_{11}}{H + E_{11} - E_{12}} \tag{9}$$

According to the expression of the volume  $V_2$  and the way of calculating the partial derivatives of the parameters: it is concluded that the incentive benefit  $I_1$ , the penalty  $F_1$ , and the cost  $G_{12}$  of the business organization nodes promote positive participation in the sharing of data elements of the business organization nodes; the cost of positive sharing  $G_{11}$  restricts the positive participation of business organization nodes in data element sharing; the effects of collaborative revenue  $H$ , positive participation in sharing revenue  $E_{11}$  and

negative participation in sharing revenue  $E_{12}$  on the participation of business organization nodes in data element sharing are related to the values of expression “ $G_{12} + I_1 + F_1 - G_{11}$ ”.

(2) Expected revenue function and replication dynamic equation of common user node

The definition of the expected revenue of the “participate in data element sharing” strategy of the common user node is  $Q_1$ , the expected revenue of the “not participate in data element sharing” strategy is  $Q_2$ , the average expected revenue is  $\bar{Q}$ , and the calculation formula is:

$$Q_1 = x * z * (E_2 + I_2 + H - G_2) + x * (1 - z) * (E_2 + I_2 + H - G_2) + (1 - x) * z * (E_2 + I_2 - G_2) + (1 - x) * (1 - z) * (E_2 + I_2 - G_2) = x * H + E_2 + I_2 - G_2 \tag{10}$$

$$Q_2 = 0 \tag{11}$$

$$\bar{Q} = y * Q_1 + (1 - y) * Q_2 = y * (x * H + E_2 + I_2 - G_2) \tag{12}$$

The replication dynamic equation of the game strategy of the common user node is:

$$F(y) = \frac{dy}{dt} = y * (Q_1 - \bar{Q}) = y * [x * H + E_2 + I_2 - G_2 - y * (x * H + E_2 + I_2 - G_2)] = y * (1 - y) * (x * H + E_2 + I_2 - G_2) \tag{13}$$

The first derivative of the replication dynamic equation  $F(y)$  of the common user node is:

$$F'(y) = \frac{dF(y)}{dy} = (1 - 2y) * (x * H + E_2 + I_2 - G_2) \tag{14}$$

Let  $L(x) = x * H + E_2 + I_2 - G_2$ , we can obtain  $L'(x) = H > 0$ , so the function  $L(x)$  is increasing with respect to  $x$ .

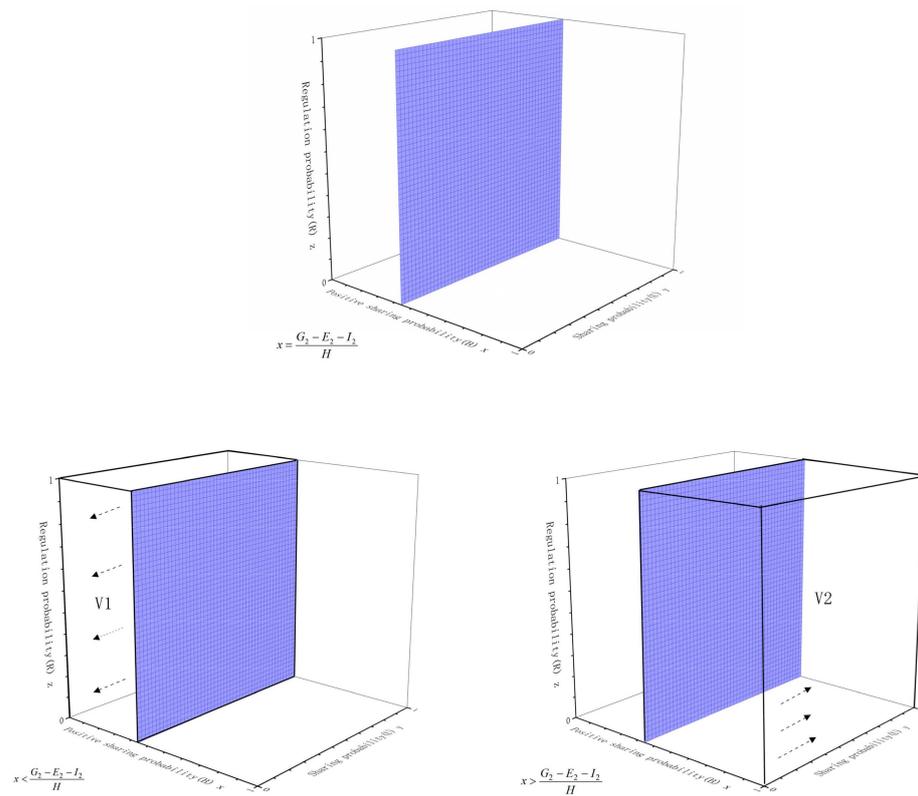
Let  $F(y) = 0$ , we can obtain:  $y = 0$  or  $y = 1$  or  $x = x^* = \frac{G_2 - E_2 - I_2}{H}$ .

- ① When  $x = x^*$ , for any  $y(0 \leq y \leq 1)$ , we can obtain  $F(y) = 0$ , and it indicates that all the policies meeting the constraints of the common user node are in a stable state, and the common user node chooses to participate in the sharing probability  $y$  will not change over time.
- ② When  $x \neq x^*$ ,  $y = 0$  or  $y = 1$  are the two evolutionary stability strategies of common user node, the distribution values of  $F'(y)$  should be discussed:
  - a. When  $\frac{G_2 - E_2 - I_2}{H} > 1$ , because  $0 \leq x \leq 1$ , so  $x < x^*$ . According to the monotonicity of the function  $L(x)$ , we obtain  $L(x) < 0$ , and then we can obtain  $F'(0) < 0$  and  $F'(1) > 0$ , so  $y = 0$  is an evolutionary stable point, which indicates that the increased revenue of the common user node is less than the increased cost of the participation in sharing, and the not participation in sharing of the common user node is the evolutionary stability strategy.
  - b. When  $\frac{G_2 - E_2 - I_2}{H} < 0$ , because  $0 \leq x \leq 1$ , so  $x > x^*$ . According to the monotonicity of the function  $L(x)$ , we can obtain  $F'(0) > 0$  and  $F'(1) < 0$ , so  $y = 1$  is an evolutionary stable point, which indicates that the increased revenue of the common user node is more than the increased cost of the participation in sharing, and the participation in sharing of the common user node is the evolutionary stability strategy.
  - c. When  $0 < \frac{G_2 - E_2 - I_2}{H} < 1$ , it was also necessary to discuss the size relationship between  $x$  and  $x^*$ :

When  $x < x^*$ , we can obtain  $F'(0) < 0$  and  $F'(1) > 0$ , so  $y = 0$  is an evolutionary stable point.

When  $x > x^*$ , we can obtain  $F'(0) > 0$  and  $F'(1) < 0$ , so  $y = 1$  is an evolutionary stable point.

Phase diagram of common user node’s strategy evolution is shown in Figure 6.



**Figure 6.** Phase diagram of common user node’s strategy evolution.

According to the figure above, the probability of selecting not to participate in data element sharing is volume  $V_1$ , and the probability of participation in data element sharing is volume  $V_2$ . The projection interval of the surface  $x = \frac{G_2 - E_2 - I_2}{H}$  onto the  $yo$ z plane is  $0 \leq y \leq 1, 0 \leq z \leq 1$ . So the volume  $V_1$  calculation formula is as follows:

$$V_1 = \int_0^1 \int_0^1 \frac{G_2 - E_2 - I_2}{H} dx dy = \int_0^1 \left( \frac{G_2 - E_2 - I_2}{H} \right) dy = \frac{G_2 - E_2 - I_2}{H} \quad (15)$$

$$V_2 = 1 - V_1 = 1 + \frac{E_2 + I_2 - G_2}{H} \quad (16)$$

According to the expression of the volume  $V_2$  and the way of calculating the partial derivatives of the parameters: it is concluded that the revenue of common user nodes participating in sharing  $E_2$  and the incentive revenue of the system  $I_2$  promoted the participation of common user nodes in data element sharing; the cost of common user nodes participating in the sharing of data elements  $G_2$  restricts the participation of common user nodes; the effect of collaborative revenue  $H$  on the participation of common user nodes in data element sharing is related to the values of the expression “ $E_2 + I_2 - G_2$ ”.

(3) Expected revenue function and replication dynamic equation of regulator node.

The definition of the expected revenue of the “participating in data element sharing regulation” strategy of the regulator node is  $R_1$ , the expected revenue of the “not participating in data element sharing regulation” strategy is  $R_2$ , the average expected revenue is  $\bar{R}$ , and the calculation formula is:

$$\begin{aligned} R_1 &= x * y * [R * (1 + \alpha + \beta) - G_3] + x * (1 - y) * [R * (1 + \alpha) - G_3] + (1 - x) * y * [R * (1 + \beta) - G_3] + (1 - x) * (1 - y) * (R - G_3) \\ &= x * R * \alpha + y * R * \beta + R - G_3 \end{aligned} \quad (17)$$

$$\begin{aligned}
 R_2 &= x * y * (-F_3) + x * (1 - y) * (-F_3) + (1 - x) * y * (-F_3) + (1 - x) * (1 - y) \\
 &\quad * (-F_3) \\
 &= -F_3
 \end{aligned}
 \tag{18}$$

$$\begin{aligned}
 \bar{R} &= z * R_1 + (1 - z) * R_2 \\
 &= z * (x * R * \alpha + y * R * \beta + R - G_3) - (1 - z) * F_3
 \end{aligned}
 \tag{19}$$

The replication dynamic equation of the game strategy of the regulator node is:

$$\begin{aligned}
 F(z) &= \frac{dz}{dt} = z * (R_1 - \bar{R}) \\
 &= z * (x * R * \alpha + y * R * \beta + R - G_3) - z * [z * (x * R * \alpha + y * R * \beta + R - G_3) - \\
 &\quad (1 - z) * F_3] \\
 &= z * (1 - z) * (x * R * \alpha + y * R * \beta + R - G_3 + F_3)
 \end{aligned}
 \tag{20}$$

The first derivative of the replication dynamic equation  $F(z)$  of the regulator node is:

$$F'(z) = \frac{dF(z)}{dz} = (1 - 2z) * (x * R * \alpha + y * R * \beta + R - G_3 + F_3)
 \tag{21}$$

Let  $L(x, y) = x * R * \alpha + y * R * \beta + R - G_3 + F_3$ , then  $\frac{\partial L}{\partial x} = R * \alpha$ , we can obtain  $\frac{\partial L}{\partial x} > 0$ , so the function  $L(x, y)$  is increasing with respect to  $x$ ;  $\frac{\partial L}{\partial y} = R * \beta$ , we can obtain  $\frac{\partial L}{\partial y} > 0$ , so the function  $L(x, y)$  is increasing with respect to  $y$ .

Let  $F(z) = 0$ , then we can obtain:  $z = 0$  or  $z = 1$  or  $x = x^* = \frac{G_3 - F_3 - R - y * R * \beta}{R * \alpha}$  ( $y = y^* = \frac{G_3 - F_3 - R - x * R * \alpha}{R * \beta}$ ).

- ① When  $x = x^*$  or  $y = y^*$ , for any  $z(0 \leq z \leq 1)$ , we can obtain:  $F(z) = 0$ , which indicates that all the policies meeting the constraints of the regulator node are in a stable state, and the regulator node chooses to participate in the sharing regulation probability  $z$  will not change over time.
- ② When  $x \neq x^*$  and  $y \neq y^*$ ,  $z = 0$  or  $z = 1$  are the two evolutionary stability strategies of the regulator node, and the distribution values of  $F'(z)$  should be discussed:
  - a. When  $\frac{G_3 - F_3 - R - y * R * \beta}{R * \alpha} > 1$  ( $\frac{G_3 - F_3 - R - x * R * \alpha}{R * \beta} > 1$ ), because  $0 \leq z \leq 1$ , so we can obtain:  $x < x^*$  ( $y < y^*$ ). According to the monotonicity of the function  $L(x, y)$ , we obtain  $L(x, y) < 0$ , and then we can obtain  $F'(0) < 0$  and  $F'(1) > 0$ , so  $z = 0$  is an evolutionary stable point, which indicates that the increased revenue of the regulator node is less than the increased cost of the participation in regulation, and the not participation in regulation of the regulator node is the evolutionary stability strategy.
  - b. When  $\frac{G_3 - F_3 - R - y * R * \beta}{R * \alpha} < 0$  ( $\frac{G_3 - F_3 - R - x * R * \alpha}{R * \beta} < 0$ ), because  $0 \leq z \leq 1$ , so we can obtain:  $x > x^*$  ( $y > y^*$ ). According to the monotonicity of the function  $L(x, y)$ , we obtain  $L(x, y) > 0$ , and then we can obtain  $F'(0) > 0$  and  $F'(1) < 0$ , so  $z = 1$  is an evolutionary stable point, which indicates that the increased revenue of the regulator node is more than the increased cost of the participation in regulation, and the participation in regulation of the regulator node is the evolutionary stability strategy.
  - c. When  $0 < \frac{G_3 - F_3 - R - y * R * \beta}{R * \alpha} < 1$  ( $0 < \frac{G_3 - F_3 - R - x * R * \alpha}{R * \beta} < 1$ ), it was also necessary to discuss the size relationship between  $x$  and  $x^*$  ( $y$  and  $y^*$ ):

When  $0 < \frac{G_3 - F_3 - R - y * R * \beta}{R * \alpha} < 1$ :

If  $x < x^*$ , we can obtain:  $F'(0) < 0$  and  $F'(1) > 0$ , so  $z = 0$  is an evolutionary stable point.

If  $x > x^*$ , we can obtain:  $F'(1) < 0$  and  $F'(0) > 0$ , so  $z = 1$  is an evolutionary stable point.

When  $0 < \frac{G_3 - F_3 - R - x * R * \alpha}{R * \beta} < 1$ :

If  $y < y^*$ , we can obtain:  $F'(0) < 0$  and  $F'(1) > 0$ , so  $z = 0$  is an evolutionary stable point.

If  $y > y^*$ , we can obtain:  $F'(1) < 0$  and  $F'(0) > 0$ , so  $z = 1$  is an evolutionary stable point.

Phase diagram of regulator node's strategy evolution is shown in Figure 7.

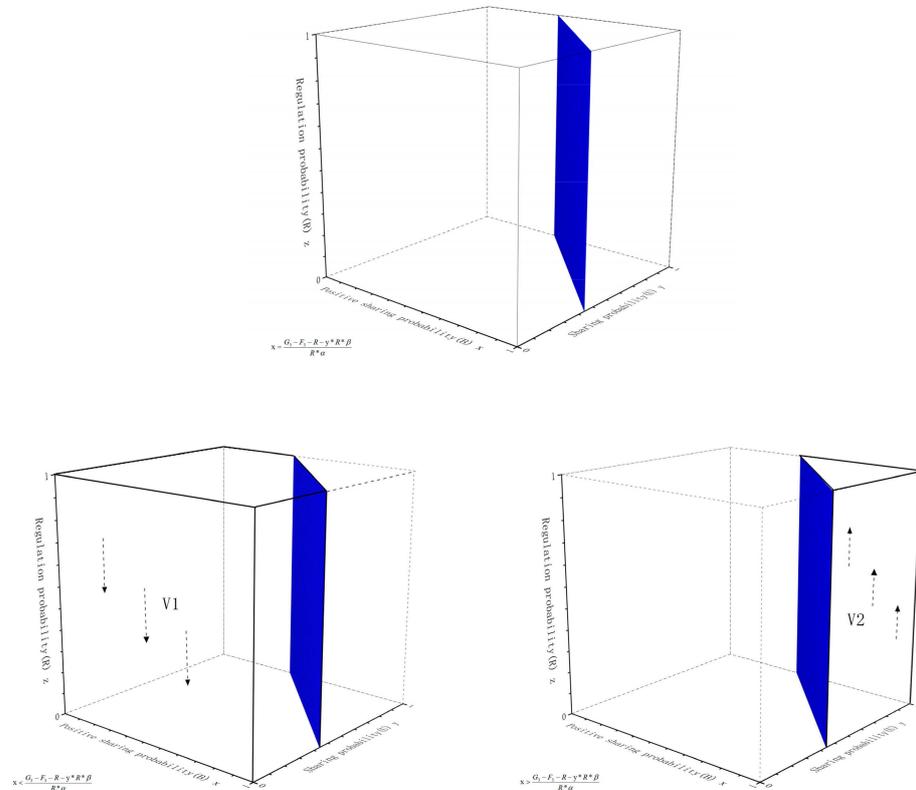


Figure 7. Phase diagram of regulator node's strategy evolution.

According to the figure above, the probability of selecting not to participate in data element sharing regulation is volume  $V_1$ , and the probability of participating in data element sharing regulation is volume  $V_2$ . The projection interval of the surface  $x = \tau(y) = \frac{G_3 - F_3 - R - y * R * \beta}{R * \alpha}$  onto the  $yz$  plane is  $0 \leq z \leq 1, \rho \leq y \leq \delta (\rho < \delta, 0 \leq \rho \leq 1, 0 \leq \delta \leq 1)$ . Set  $y = \tau^{-1}(x)$  is the inverse function of  $x = \tau(y)$ , then  $\delta$  and  $\rho$  satisfy the following conditions:

$$\rho = \begin{cases} \tau^{-1}(1) & \tau(0) \geq 1 \\ 0 & \tau(0) < 1 \end{cases} \tag{22}$$

$$\delta = \begin{cases} 1 & \tau^{-1}(0) \geq 1 \\ \tau^{-1}(0) & \tau^{-1}(0) < 1 \end{cases} \tag{23}$$

The volume  $V_1$  calculation formula is as follows:

$$\begin{aligned} V_1 &= \int_0^1 \int_{\rho}^{\delta} \frac{G_3 - F_3 - R - y * R * \beta}{R * \alpha} dy dz \\ &= \int_0^1 \left[ \frac{-(F_3 + R + \beta * R * y - G_3)^2}{2 * \alpha * \beta * R^2} + C \right] \Big|_{\rho}^{\delta} dz \\ &= \frac{(F_3 + R + \beta * R * \rho - G_3)^2 - (F_3 + R + \beta * R * \delta - G_3)^2}{2 * \alpha * \beta * R^2} \end{aligned} \tag{24}$$

where  $C$  is the integral constant.

$$V_2 = 1 - V_1 - V_3 = 1 + \frac{(F_3 + R + \beta * R * \delta - G_3)^2 - (F_3 + R + \beta * R * \rho - G_3)^2}{2 * \alpha * \beta * R^2} - V_3 \tag{25}$$

where  $V_3$  is the constant of  $\rho$  and  $\delta$ .

According to the expression of the volume  $V_2$  and the way of calculating the partial derivatives of the parameters, it is concluded that the punishment of regulator nodes not participating in sharing regulation  $F_3$  promoted the participation of regulator nodes in data element sharing regulation; the cost of regulator nodes participating in the sharing regulation  $G_3$  restricts the participation in the regulation of regulator nodes; the effect of regulation revenue  $R$  on the participation of regulator nodes in data element sharing regulation is related to the values of the expression " $F_3 - G_3$ ".

#### 4. Results and Discussion

##### 4.1. Evolutionary Stable Strategy

The evolutionary stable strategy was proposed by Maynard Smith in 1973 based on the principle of natural selection in Darwin's theory of biological evolution. In detail, it means that when all individuals in a population adopt the same behavior strategy, under the influence of natural selection, this population can resist any mutation strategy invading the population from inside or outside, that is to say, in an evolutionary game system, any individual in the system, under the limited payoff information, through repeated games, constantly adjust their strategy selection according to their existing interests, so as to maximize their own interests. Finally, in order to maintain their own interests, a dynamic equilibrium state is reached. In this dynamic equilibrium state, every individual in the system is no longer willing to change their strategy, and the strategy formed in this state is an evolutionary, stable strategy [59].

Based on the stability analysis of the single agent strategy, the stability of the equilibrium point of the tripartite subject evolutionary game system is further analyzed. According to the stability theorem of the differential equation of the evolutionary game, in order to keep a strategy in a stable state, the probability of the game party choosing the strategy must meet the replication dynamic equation equal to 0, and the first derivative is less than 0. The point that meets such a condition is the equilibrium point of the evolutionary game. When the equilibrium point satisfies certain conditions, then the equilibrium point is the evolutionary stability strategy of the dynamic evolutionary game. According to the Lyapunov discrimination method, when the eigenvalue  $\lambda$  surpasses zero, the equilibrium point is unstable, and the point is the source point; when the eigenvalue  $\lambda$  encompasses both positive and negative values, the equilibrium point is unstable, and the point is the saddle point; when the eigenvalue  $\lambda$  falls below zero, the equilibrium point maintains stability and functions as a junction point, which also signifies the point's stability in terms of evolution. [33,60].

To simplify the operation, we set  $H + E_{11} - E_{12} = \varphi_1$ ;  $I_1 + F_1 + G_{12} - G_{11} = \mu_1$ ;  $E_2 + I_2 - G_2 = \mu_2$ ;  $R * \alpha = \varphi_3$ ;  $R * \beta = \mu_3$ ;  $F_3 - G_3 = \pi_3$ . Then, the replication dynamic equation of the evolutionary game is simplified as follows:

$$\begin{cases} F(x) = x * (1 - x) * (y * \varphi_1 + \mu_1) \\ F(y) = y * (1 - y) * (x * H + \mu_2) \\ F(z) = z * (1 - z) * (x * \varphi_3 + y * \mu_3 + \pi_3) \end{cases} \tag{26}$$

The corresponding Jacobian matrix [61]  $J$  is as follows:

$$J = \begin{bmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} & \frac{\partial F(x)}{\partial z} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} & \frac{\partial F(y)}{\partial z} \\ \frac{\partial F(z)}{\partial x} & \frac{\partial F(z)}{\partial y} & \frac{\partial F(z)}{\partial z} \end{bmatrix} = \begin{bmatrix} \lambda_1(x, y, z) & x * (1 - x) * \varphi_1 & 0 \\ y * (1 - y) * H & \lambda_2(x, y, z) & 0 \\ z * (1 - z) * \varphi_3 & z * (1 - z) * \mu_3 & \lambda_3(x, y, z) \end{bmatrix} \tag{27}$$

where  $\lambda_1(x, y, z) = (1 - 2x) * (y * \varphi_1 + \mu_1)$ ,  $\lambda_2(x, y, z) = (1 - 2y) * (x * H + \mu_2)$ ,  $\lambda_3(x, y, z) = (1 - 2z) * (x * \varphi_3 + y * \mu_3 + \pi_3)$ .

The equilibrium point is solved according to the replication dynamic equation:

$$\begin{cases} F(x) = 0 \\ F(y) = 0 \\ F(z) = 0 \end{cases} \tag{28}$$

On the basis of Formula (26), we can obtain the equilibrium points for the system: E1(0,0,0), E2(0,0,1), E3(0,1,0), E4(0,1,1), E5(1,0,0), E6(1,0,1), E7(1,1,0), E8(1,1,1). On the basis of Formula (27), we can obtain the local equilibrium point, eigenvalue distribution and stability conditions of the model, as shown in the following Table 3.

**Table 3.** The equilibrium points correspond to eigenvalues and stability conditions.

Equilibrium Points	Eigenvalues			Stability Conditions
	$\lambda_1$	$\lambda_2$	$\lambda_3$	
E1(0,0,0)	$\mu_1$	$\mu_2$	$\pi_3$	$I_1 + F_1 + G_{12} < G_{11}$ $E_2 + I_2 < G_2$ $F_3 < G_3$
E2(0,0,1)	$\mu_1$	$\mu_2$	$-\pi_3$	$I_1 + F_1 + G_{12} < G_{11}$ $E_2 + I_2 < G_2$ $F_3 > G_3$
E3(0,1,0)	$\varphi_1 + \mu_1$	$-\mu_2$	$\mu_3 + \pi_3$	$H + E_{11} + I_1 + F_1 + G_{12} < G_{11} + E_{12}$ $E_2 + I_2 > G_2$ $R * \beta + F_3 < G_3$
E4(0,1,1)	$\varphi_1 + \mu_1$	$-\mu_2$	$-\mu_3 - \pi_3$	$H + E_{11} + I_1 + F_1 + G_{12} < G_{11} + E_{12}$ $E_2 + I_2 > G_2$ $R * \beta + F_3 > G_3$
E5(1,0,0)	$-\mu_1$	$H + \mu_2$	$\varphi_3 + \pi_3$	$I_1 + F_1 + G_{12} > G_{11}$ $H + E_2 + I_2 < G_2$ $R * \alpha + F_3 < G_3$
E6(1,0,1)	$-\mu_1$	$H + \mu_2$	$-\varphi_3 - \pi_3$	$I_1 + F_1 + G_{12} > G_{11}$ $H + E_2 + I_2 < G_2$ $R * \alpha + F_3 > G_3$
E7(1,1,0)	$-\varphi_1 - \mu_1$	$-H - \mu_2$	$\varphi_3 + \mu_3 + \pi_3$	$H + E_{11} + I_1 + F_1 + G_{12} > G_{11} + E_{12}$ $H + E_2 + I_2 > G_2$ $R * (\alpha + \beta) + F_3 < G_3$
E8(1,1,1)	$-\varphi_1 - \mu_1$	$-H - \mu_2$	$-\varphi_3 - \mu_3 - \pi_3$	$H + E_{11} + I_1 + F_1 + G_{12} > G_{11} + E_{12}$ $H + E_2 + I_2 > G_2$ $R * (\alpha + \beta) + F_3 > G_3$

According to the judgment of Table 3, we selected several special equilibrium points for sampling analysis in this paper: E1(0,0,0), E2(0,0,1), E7(1,1,0) and E8(1,1,1).

Inference 1: Under condition a,  $I_1 + F_1 + G_{12} < G_{11}$ ,  $E_2 + I_2 < G_2$ ,  $F_3 < G_3$ , the replication dynamic system has stable points, E1(0,0,0). Under condition b,  $I_1 + F_1 + G_{12} < G_{11}$ ,  $E_2 + I_2 < G_2$ ,  $F_3 > G_3$ , the replication dynamic system has stable points, E2(0,0,1).

Proof: According to the Lyapunov discriminant method, condition a and condition b, the eigenvalues  $\lambda_1, \lambda_2, \lambda_3$  of the Jacobian matrix corresponding to the replicated dynamic system at the equilibrium points E1(0,0,0), E2(0,0,1) are all less than 0, so the equilibrium points E1(0,0,0), E2(0,0,1) are the stable points of the system.

It follows from Inference 1 that the cost of nodes participating in the sharing of ecological data elements or regulatory links plays an inhibitory role in the selection of

nodes participating in positive sharing, sharing or regulation. When the cost of participation is large enough, ecological nodes will choose negative sharing, not participate in sharing or not participate in regulation; therefore, controlling the cost of participation in sharing is an effective way to promote active sharing or regulation. The punishment for the negative sharing of the business organization node and the punishment for no regulation of the regulator node plays an important role in whether the nodes choose to positively share or participate in regulation, and when the punishment is large enough, it will urge business organization nodes and regulator nodes to choose to positively share or participate in regulation.

Inference 2: Under condition c,  $H + E_{11} + I_1 + F_1 + G_{12} > G_{11} + E_{12}$ ,  $H + E_2 + I_2 > G_2$ ,  $R * (\alpha + \beta) + F_3 < G_3$ , the replication dynamic system has stable points, E7(1,1,0). Under condition d,  $H + E_{11} + I_1 + F_1 + G_{12} > G_{11} + E_{12}$ ,  $H + E_2 + I_2 > G_2$ ,  $R * (\alpha + \beta) + F_3 > G_3$ , the replication dynamic system has stable points, E8(1,1,1).

Proof: According to the Lyapunov discriminant method, condition c and condition d, the eigenvalues  $\lambda_1, \lambda_2, \lambda_3$  of the Jacobian matrix corresponding to the replicated dynamic system at the equilibrium points E7(1,1,0), E8(1,1,1) are all less than 0, so the equilibrium points E7(1,1,0), E8(1,1,1) are the stable points of the system.

It follows from Inference 2 that the collaborative revenue of participation of the two parties and the revenue in sharing or regulation play an important role in promoting the participation or regulation. When the benefits of participation are large enough, the system nodes choose to actively participate in the sharing of data elements or regulation; the incentive revenue of nodes positively sharing or participating in sharing and the additional rate of revenue after the success of regulation play a role in promoting the participation of nodes in sharing or regulation, and when the participation revenue or the system incentive revenue is large enough, the system nodes will choose to positively participate in the data element sharing or regulation.

#### 4.2. Stable Strategy Simulation

In order to more intuitively reflect the game behavior selection of the business organization node, common user node and regulator node under the situation of data element sharing, we used Matlab(R2023a) software to conduct a numerical simulation analysis of the evolution and stability strategy of the tripartite game subjects under the change in different parameters and verify the above theoretical analysis. Due to the complexity of the convergence media ecology, the research model in this article cannot be fully validated by substitution in the convergence media ecology for the time being, which is also a shortcoming of the research content in this article. In order to verify the effectiveness of the model as accurately as possible, the model parameters in the simulation and verification process of this article are randomly generated according to the requirements to meet the general principles of the experiment.

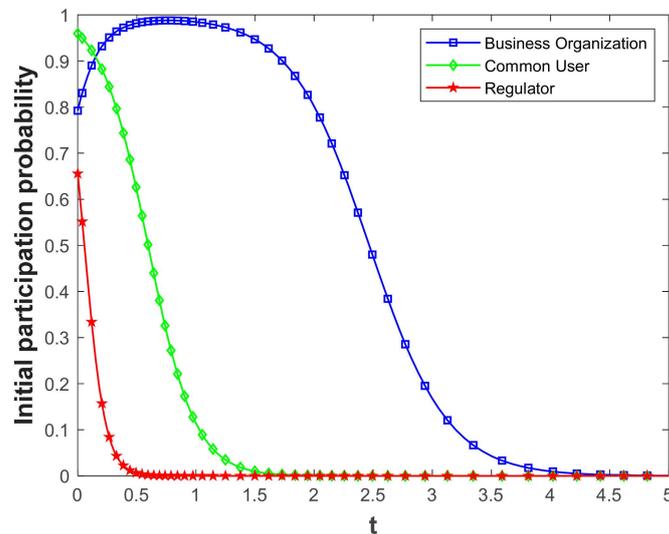
The numerical simulation foundation is set as follows: simulation time span is 0 to 5, business organization node “positively participate in data sharing” strategy probability from 0.1 to 0.9, an interval of 0.2; common user node takes the probability of the “data sharing” strategy from 0.1 to 0.9, an interval of 0.2; regulator node takes the probability of “regulation” strategy from 0.1 to 0.9, an interval of 0.2. In the tripartite evolution stability strategy simulation diagram, the blue curve represents the probability curve of the business organization node choosing to positively participate in data element sharing, the green curve represents the probability curve of the common user node choosing to participate in data element sharing, and the red curve represents the probability curve of the regulator node choosing to participate in data element sharing regulation. In this paper, we extracted four special equilibrium points, E1(0,0,0), E2(0,0,1), E7(1,1,0) and E8(1,1,1), for sampling simulation analysis. The specific values of parameter simulation are shown in Table 4.

**Table 4.** Numerical simulation value.

ID	$E_{11}$	$E_{12}$	$G_{11}$	$G_{12}$	$I_1$	$F_1$	$E_2$	$G_2$	$I_2$	R	$G_3$	$\alpha$	$\beta$	$F_3$	H
1	15	10	25	7	10	5	10	25	5	5	20	0.3	0.5	5	5
2	15	10	25	7	10	5	10	20	15	5	20	0.3	0.5	25	10
3	15	10	25	7	10	5	10	30	10	5	20	0.3	0.5	25	5
4	15	10	25	7	10	5	10	25	20	5	20	0.3	0.5	10	5

(1) Numerical simulation analysis of the equilibrium point  $E_1(0,0,0)$

When the parameter assignment of group 1 is used, the stability condition of equilibrium point  $E_1(0,0,0)$  is met. Based on this condition, numerical simulation was conducted, and the initial values of  $x, y$  and  $z$  were randomly specified. The tripartite evolutionary game stable strategy diagram is shown in Figure 8. The initial values of  $x, y$  and  $z$  are set as 0.1, 0.1 and 0.1, and the evolution is carried out according to the step size of 0.2. A tripartite evolutionary game three-dimensional simulation diagram is shown in Figure 9.



**Figure 8.** Tripartite evolutionary game stable strategy diagram of  $E_1(0,0,0)$ .

On the basis of the first set of parameter data, the values of  $G_{11}$  were set, respectively, as 25, 50 and 75, and the initial participation probabilities of the tripartite evolutionary game  $(x,y,z)$  were randomly set, and the simulation results of replicating the dynamic equations with  $G_{11}$  changes are shown in Figure 10.

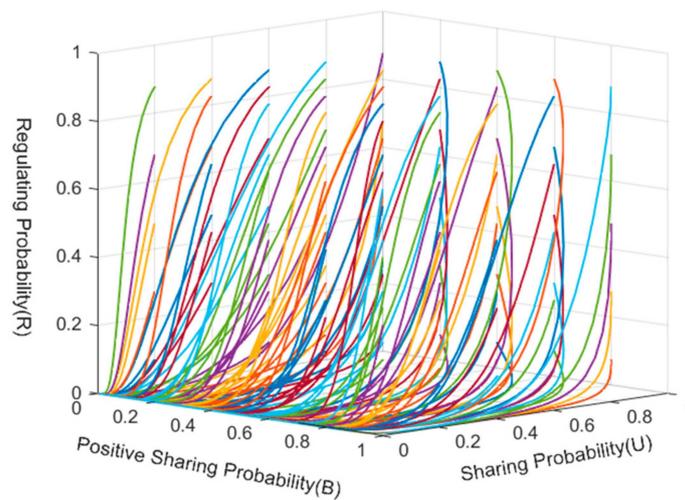


Figure 9. Tripartite evolutionary game three-dimensional simulation of E1(0,0,0).

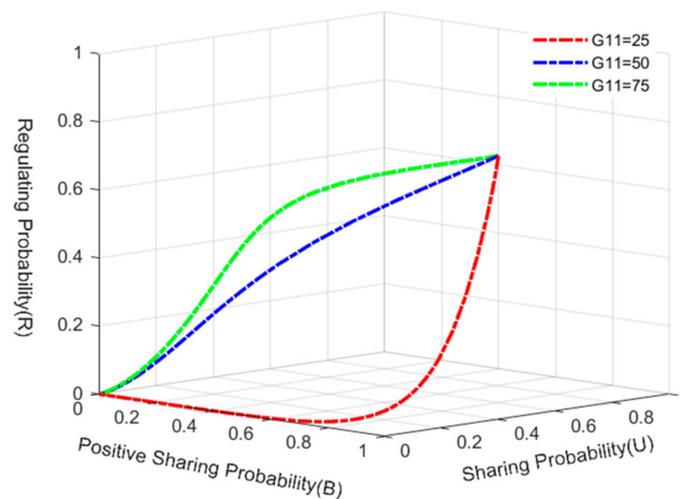


Figure 10. Impact of  $G_{11}$ .

Figure 10 shows that in the process of evolution to a stable point, as the cost of positive sharing of business organization nodes  $G_{11}$  increases, the evolution speed of negative sharing of business organization nodes will be accelerated. Therefore, reducing the cost of positive sharing is conducive to promoting positive participation in the sharing of business organization nodes.

(2) Numerical simulation analysis of the equilibrium point E8(1,1,1)

When the parameter assignment of group 2 is used, the stability condition of equilibrium point E8(1,1,1) is met. Based on this condition, numerical simulation was conducted, and the initial values of  $x$ ,  $y$  and  $z$  were randomly specified. The tripartite evolutionary game stable strategy diagram is shown in Figure 11. The initial values of  $x$ ,  $y$  and  $z$  are set as 0.1, 0.1 and 0.1, and the evolution is carried out according to the step size of 0.2. A tripartite evolutionary game three-dimensional simulation diagram is shown in Figure 12.

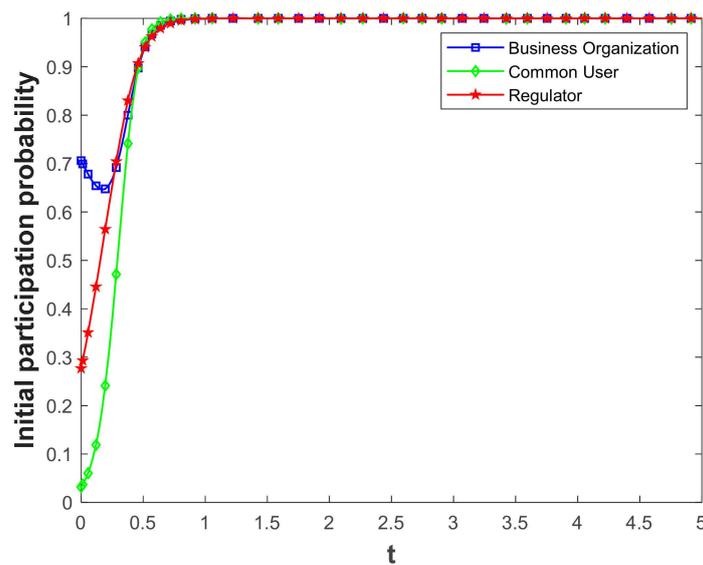


Figure 11. Tripartite evolutionary game stable strategy diagram of E8(1,1,1).

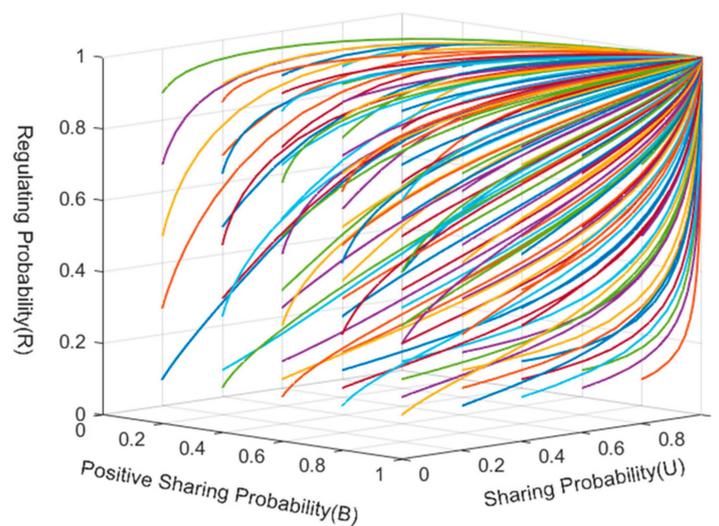


Figure 12. Tripartite evolutionary game three-dimensional simulation of E8(1,1,1).

On the basis of the second set of parameter data, the values of  $H$  were set, respectively, as 5, 15 and 45, and the initial participation probabilities of the tripartite evolutionary game  $(x,y,z)$  were randomly set, and the simulation results of replicating the dynamic equations with  $H$  changes were shown in Figure 13.

Figure 13 shows that in the process of evolution to a stable point, as the collaborative revenue  $H$  increases, the evolution speed participating in the sharing of the business organization node and common user node will be accelerated. Therefore, improving the collaborative revenue of participation in sharing is conducive to promoting positive participation in the sharing of business organization nodes and common user nodes.

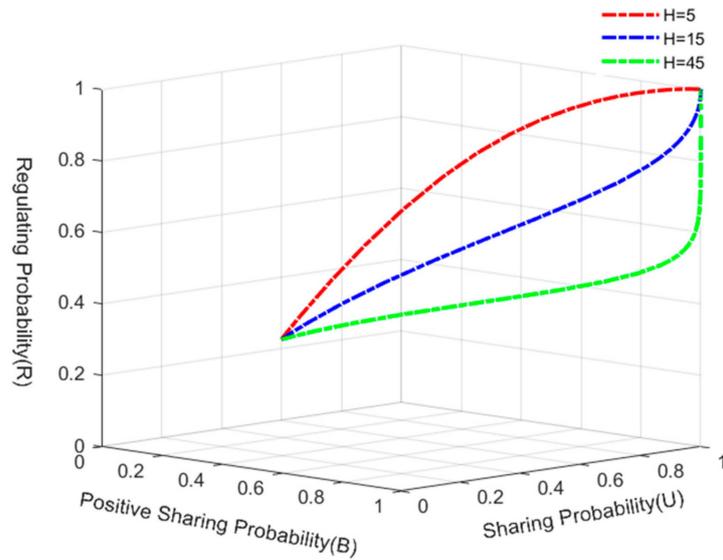


Figure 13. Impact of H.

(3) Numerical simulation analysis of the equilibrium point E2(0,0,1)

When the parameter assignment of group 3 is used, the stability condition of equilibrium point E2(0,0,1) is met. Based on this condition, numerical simulation was conducted, and the initial values of x, y and z were randomly specified. The tripartite evolutionary game stable strategy diagram is shown in Figure 14. The initial values of x, y and z are set as 0.1, 0.1 and 0.1, and the evolution is carried out according to the step size of 0.2. A tripartite evolutionary game three-dimensional simulation diagram is shown in Figure 15.

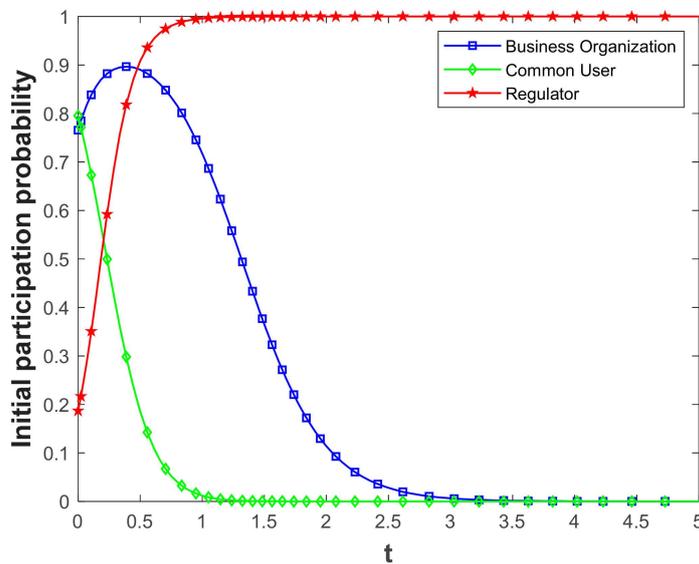
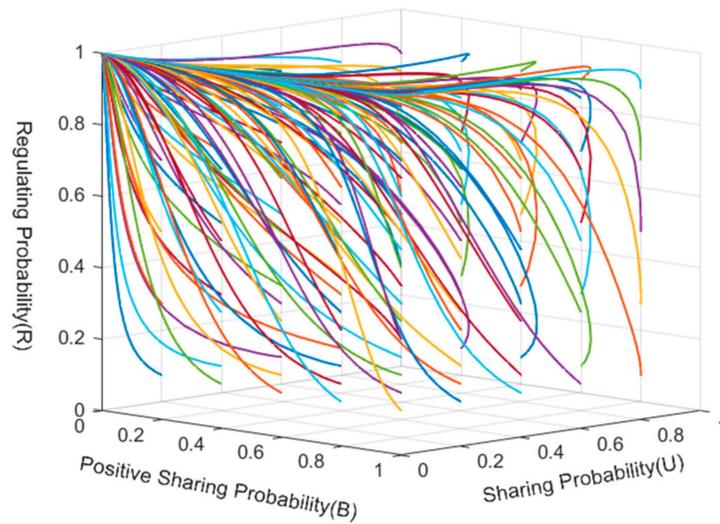
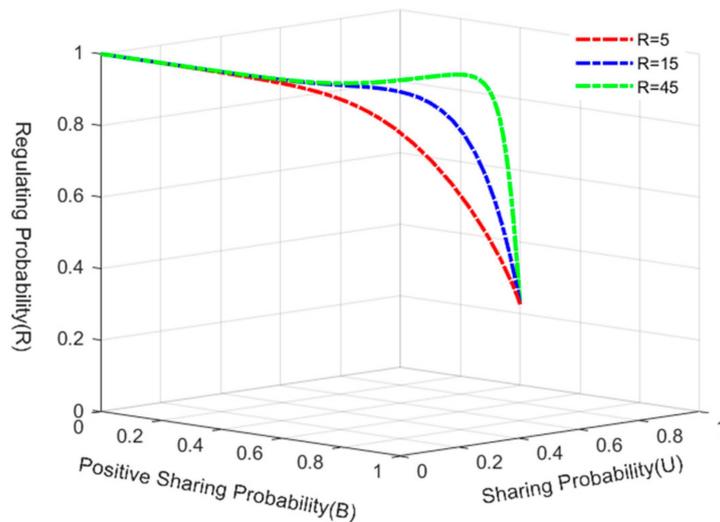


Figure 14. Tripartite evolutionary game stable strategy diagram of E2(0,0,1).



**Figure 15.** Tripartite evolutionary game three-dimensional simulation of E2(0,0,1).

On the basis of the third set of parameter data, the values of  $R$  were set, respectively, as 5, 15 and 25, and the initial participation probabilities of the tripartite evolutionary game  $(x,y,z)$  were randomly set, and the simulation results of replicating the dynamic equations with  $R$  changes are shown in Figure 16.



**Figure 16.** Impact of  $R$ .

Figure 16 shows that in the process of evolution to a stable point, as the  $R$  increases, the evolution speed participating in the regulation of the regulator node will be accelerated. Therefore, improving the  $R$  is conducive to promoting participation in the regulation of regulator nodes.

(4) Numerical simulation analysis of the equilibrium point E7(1,1,0).

When the parameter assignment of group 4 is used, the stability condition of equilibrium point E7(1,1,0) is met. Based on this condition, numerical simulation was conducted, and the initial values of  $x$ ,  $y$  and  $z$  were randomly specified. The tripartite evolutionary game stable strategy diagram is shown in Figure 17. The initial values of  $x$ ,  $y$  and  $z$  are set as 0.1, 0.1 and 0.1, and the evolution is carried out according to the step size of 0.2. A tripartite evolutionary game three-dimensional simulation diagram is shown in Figure 18.

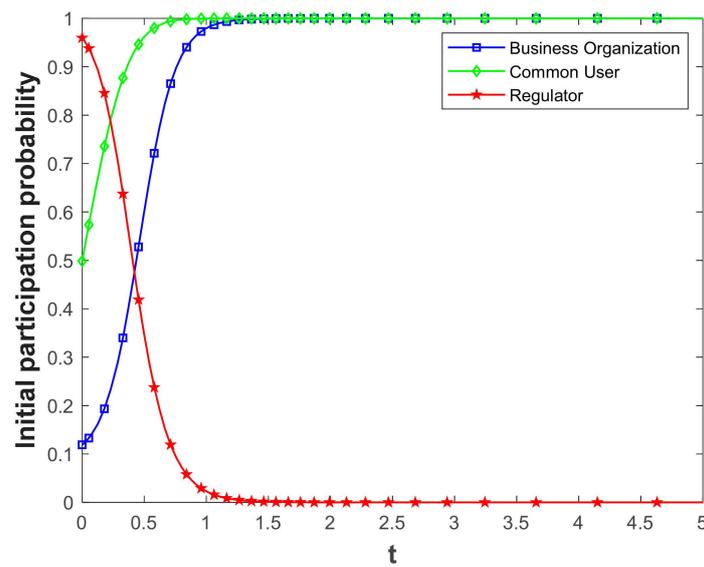


Figure 17. Tripartite evolutionary game stable strategy diagram of E7(1,1,0).

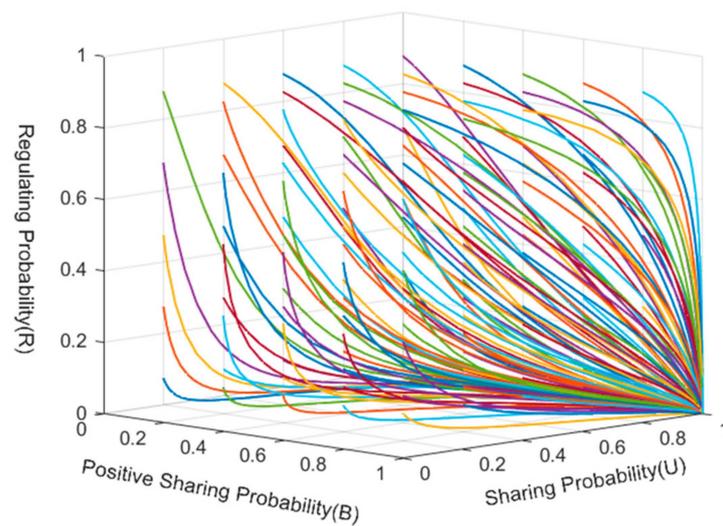


Figure 18. Tripartite evolutionary game three-dimensional simulation of E7(1,1,0).

On the basis of the fourth set of parameter data, the values of  $F_3$  were set, respectively, as 5, 10 and 15, and the initial participation probabilities of the tripartite evolutionary game  $(x,y,z)$  were randomly set, and the simulation results of replicating the dynamic equations with  $F_3$  changes are shown in Figure 19.

Figure 19 shows that in the process of evolution to a stable point, as the  $F_3$  decreases, the evolution speed not participating in the regulation of the regulator node is accelerated. Therefore, improving the  $F_3$  is conducive to promoting the participation in regulation of regulator nodes.

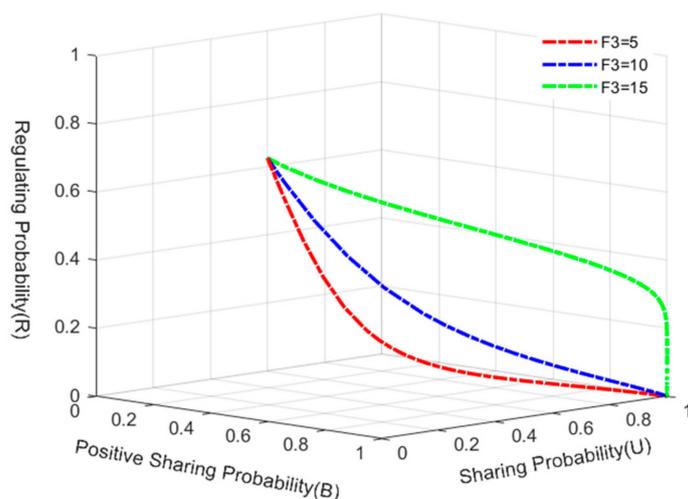


Figure 19. Impact of  $F_3$ .

### 4.3. Model Comparison

At present, game theory has some mature application cases in finance, the Internet, medicine and other fields, but relatively few applications in the media field. The complexity of media data circulation, the diversity of media organizations, and the diversity of user behaviors increase the complexity of the application of game theory in the media industry. The model design in this article is based on evolutionary game theory, combines the industry attributes of nodes in the media ecology and introduces the role of regulators in order to adapt to the particularity of the media industry. In this article, the data element sharing model of convergence media ecology based on the evolutionary game is compared with the other three similar models, and the specific contents are shown in the following table. Similar model comparison is shown in Table 5.

Table 5. Similar model comparison.

Indicator	Indicator Advantage	Alipour-Vaezi, M [62]	Wang, E. K [63]	Xu, Z. Q. [64]	Wang, JG [65]	This Article
Industry	Adapt to industry characteristics	Media	Intenet	Medical	Retail	Media
Stability strategy	Strategy guidance	FALSE	TRUE	TRUE	TRUE	TRUE
Based on media	Adapt to the characteristics of the media industry	TRUE	FALSE	FALSE	FALSE	TRUE
Regulator node	Adapt to media industry standards	FALSE	FALSE	TRUE	TRUE	TRUE
Data element requirement	Adaptive data circulation	TRUE	FALSE	FALSE	FALSE	TRUE
Degree of node participation	Promoting model activity	FALSE	TRUE	FALSE	FALSE	TRUE
Node credit	Guarantee node credit	FALSE	TRUE	FALSE	FALSE	TRUE
Incentive strategy	Encourage nodes to participate actively	FALSE	TRUE	FALSE	TRUE	TRUE
Penalty strategy	Maintain the balance of ecological values	FALSE	TRUE	TRUE	TRUE	TRUE

Table 5. Cont.

Indicator	Indicator Advantage	Alipour-Vaezi, M [62]	Wang, E. K [63]	Xu, Z. Q. [64]	Wang, JG [65]	This Article
Artificial intelligence-based	Model intelligence	TRUE	FALSE	FALSE	FALSE	FALSE
Network attack defense	Ensure network security	FALSE	TRUE	FALSE	FALSE	FALSE
Model verification	The way of verification	Analysis and Discussion	Simulation Evaluation	Numerical Simulation	Numerical Simulation	Numerical Simulation

From the comparison of the correlation models above, it can be seen that the model in this article has certain advantages in the application of convergence media ecology, which can reflect the media attributes related to nodes so as to encourage nodes to actively participate in data element sharing. At the same time, supervision nodes are introduced from the perspective of industry characteristics so as to ensure that the model is more suitable for industry standards. However, the model in this article needs further study in the aspects of artificial intelligence and network security.

## 5. Conclusions

This paper studied the development status of convergence media ecology, analyzed and summarized some problems faced by convergence media ecology in data element sharing, such as the insufficient activity of the convergence media ecology, the incomplete circulation mechanism of data elements and the inadequate implementation of the reward and punishment mechanism which have become essential factors restricting the healthy development of the convergence media ecology. Therefore, activating the sharing willingness of nodes and promoting the sharing of data elements between nodes has become the primary key to solving the existing problems.

Based on the analysis of the existing problems, this paper proposed the solution of introducing the evolutionary game into the convergence media ecology. According to the ecological characteristics of nodes, we established the node classification mode of the evolutionary game and the data element sharing model based on the evolutionary game; then, we analyzed the payoff of nodes under this model and presented the payoff matrix, expected payoff function and replication dynamic equation of the data element sharing evolutionary game. According to the replication dynamic equation of nodes, the evolution path of different types of nodes in the model is analyzed, and the stability point of the evolutionary game, the evolutionary stability strategy and the corresponding node state conditions are also proposed. Based on the design and analysis of the convergence media ecological data element sharing evolutionary game mode, this paper used Matlab to conduct a sampling simulation experiment on the model design and analysis and verified the research results, which showed the effectiveness of the research content of this paper. Studies and experiments showed that:

- (1) For business organization nodes, incentive revenue of positive participation in sharing  $I_1$ , negative sharing punishment  $F_1$  and negative sharing cost  $G_{12}$  play a promoting role in positively participating in data element sharing; the cost of positively share  $G_{11}$  restricts the positive participation in data element sharing; collaborative revenue  $H$ , the revenue of positively participating in sharing  $E_{11}$  and the revenue of negative participation in sharing  $E_{12}$  are not fixed on the influence of the business organization node, affected by the state of other parameters.
- (2) For common user nodes, the revenue from participating in the sharing  $E_2$  and the system incentive revenue  $I_2$  for a common user node play a promoting role in participating in data element sharing; the cost of participating in sharing  $G_2$  restricts the participation of the common user node in data element sharing; collaborative revenue

$H$  is not fixed on the influence of the business organization node, affected by the state of other parameters.

- (3) For the regulator node, the punishment for not participating  $F_3$  plays a promoting role in participating in data element sharing regulation; the cost of regulation  $G_3$  restricts the participation in data element sharing regulation; the revenue of regulation  $R$  is not fixed on the influence of the regulator node, affected by the state of other parameters.
- (4) The probability of business organization nodes choosing to participate in positively sharing is complementary to the probability of common user nodes choosing to participate in sharing, which increases with the increase in the participation probability of the other party.
- (5) According to the model presented in this paper, the ecological nodes finally reach the corresponding evolutionary stability strategy under the corresponding state conditions, and the research results can provide solutions to solve the problem of nodes not participating in data element sharing or supervision faced by ecological development.

This paper enriches the research on the sharing of data elements in convergence media ecology and explores the willingness and tendency of all participants. The research results can provide targeted suggestions for promoting the sharing of data elements in convergence media ecology:

- (1) In promoting the sharing of data elements, it is necessary to formulate standardized behavior rules and regulatory implementation plans to prevent the implementation of behavioral rules so as to improve the confidence of nodes in sharing data elements in ecology and lay a foundation for promoting the sharing of data element in convergence media ecology.
- (2) The system needs reasonable planning; severe punishment may hinder nodes from joining ecological and participating in the data sharing attempt, and low punishment cannot play a guiding role in the ecosystem. High system incentives will destroy the ecological balance of the system, and low system incentives cannot stimulate the participation of the node.
- (3) The model evolution path analysis and macro-control of the state parameters of the corresponding nodes under specific state conditions should be made good use of so as to promote the ecological nodes to positively participate in the data element sharing.

The data element sharing model of convergence media ecology based on the evolutionary game proposed in this paper is characterized by individual limited rationality, incentive compatibility, real-time and scalability, and has a low computational cost and good practicability. At the same time, although this paper has entered into thorough research on the sharing of data elements in convergence media ecology, there are still some deficiencies, such as the failure to study the specific implementation of the evolutionary game model, which will be further improved in the subsequent research.

**Author Contributions:** Conceptualization, Y.W.; methodology, H.H. and Y.W.; formal analysis, G.S.; investigation, C.L.; writing—original draft preparation, H.H.; writing—review and editing, Y.W.; visualization, W.F.; project administration, Y.W.; funding acquisition, Y.W. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by the Beijing Social Science Fund key project, grant number 23JCB002.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Data are contained within the article.

**Acknowledgments:** The authors greatly appreciate the editor and anonymous reviewers for their comments, which helped to improve this paper.

**Conflicts of Interest:** The authors declare no conflict of interest.

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