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How to Enhance Data Sharing in Digital Government Construction: A Tripartite Stochastic Evolutionary Game Approach

Changqi Dong, **Jida Liu** * and **Jianing Mi**

School of Management, Harbin Institute of Technology, Harbin 150001, China
* Correspondence: kittadada@yeah.net

Abstract: Digital government construction is a complex system project, and data sharing is its governance niche. Cross-sectoral data sharing is the core issue of improving governance capacity in the construction of digital governments. Aimed at the dilemma of insufficient data sharing across departments, according to evolutionary game theory (EGT), we refined the game relationship between the data management department and the different government functional departments participating in cross-department data sharing. We used white Gaussian noise as a random perturbation, constructed a tripartite stochastic evolutionary game model, analyzed the stability of the stochastic game system and studied the influence of the main parameters on the evolution of the game system with the help of numerical simulation. The results show that there exists a positive stable point in the process of cross-department data sharing. The external effect of data sharing can be improved by enhancing the investment in data sharing by government functional departments. The accumulation of inter-agency trust relationships can gradually eliminate the differences in data sharing among different departments. The coordination mechanism of government data sharing and the construction of the "good and bad reviews" system can form an internal and external adjustment mechanism for functional departments and the data management department and can promote multiple departments to participate in cross-department data sharing more actively.

Keywords: data sharing; cross-department coordination; data management; digital government; stochastic evolutionary game

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1. Introduction

With the advent of the Fourth Industrial Revolution, the digital economy is experiencing an extraordinary boom, leading to a similar transformation of digital government in the area of government governance [1]. In this context of development, the traditional discourse on production relations in the political economy is being further expanded, with data becoming a vital means of production [2]. The widespread adoption and application of digital technology has resulted in organizational and managerial changes, particularly in government departments in which information technology changes have brought a gradual shift in the paradigm of administrative governance toward governance in the digital age [3]. Compared to the deconstruction approach of new public management (NPM), which aims to create small, fragmented institutional governance, the digital government era focuses on reintegration and needs-based holism. This approach relies on digital technology to enhance collaborative governance across sectors, thereby re-governmentalizing and attempting to eliminate silos of public sector processes. This helps prevent administrative fragmentation dilemmas [4]. In the progress of building a digital government, realizing the convergence and sharing of data elements across departments, regions and fields has become a core issue in enhancing the governance capacity of digital government.

To achieve integrated data management and construct a collaborative and open digital government management platform, data management departments have been established in different regions of China. These departments can be classified into three types: independent government departments with data management functions, established departments that have added data management functions, and new divisions that have incorporated data management functions under one of the original departments [5]. A common challenge faced by different types of data management departments is the relationship with functional departments [6,7]. On the one hand, the degree of informatization varies from department to department. The digital literacy and competence of public officials varies, as does the degree of standardization and differentiation of data in the sector. On the other hand, regarding sharing data, decision makers in a department assess the risks involved and are torn between active and passive sharing, or even nonsharing, as they see data as core assets for maintaining power [8]. The priority of whether this sharing affects the core interests of the department is clearly higher for departmental heads than the overall performance of the digital government [9].

Cross-department data sharing is a dynamic and complex game process containing many uncertain and unstable factors. In order to analyze in detail the strategic paths of the different subjects in this game process and the influence of relevant factors, this paper constructed a tripartite evolutionary game model and introduced Gaussian white noise to simulate the random disturbance environment, and the changes and stability conditions of the data sharing game strategy between the data management departments and the different government functional departments are discussed. Furthermore, we used a numerical simulation to analyze the trajectory of the evolution of the strategy of the different subjects under the influence of multiple factors in a stochastic environment. We provide specific recommendations based on the findings of this study to promote smooth data sharing among different sectors with the expectation of advancing digital governance capabilities in the era of big data. From the existing studies, it can be seen that the role played by data management departments in data sharing and their influencing factors have received extensive focus, especially the relationship between data management departments and functional departments, which has also been somewhat elucidated from the qualitative research perspective. However, it should be emphasized that inter institutional relationships are not static. Especially in the complex environment of digital transformation, the behavioral performance and strategic choices of data management departments and functional departments change dynamically with the influence of different factors. Therefore, we consider introducing evolutionary game theory into the study of this paper to characterize the cross-department data sharing system and its evolutionary process.

The remainder of the research in this paper is arranged as follows: Section 2 provides a review of the relevant research on cross-department data sharing, including the current dilemma and influencing factors of cross-sector data sharing and the applicability of stochastic evolutionary game models in this paper. In Section 3, we present seven basic assumptions for carving out the game process of cross-department data sharing and build a traditional evolutionary game model based on them. In Section 4, we introduce Gaussian white noise to improve the traditional evolutionary game model by giving it a stochastic character. Section 5 uses simulation tools to analyze the behavioral evolution of the data management departments and the government functional departments under different influencing factors. Section 6 contains a further discussion of the simulation results. Section 7 presents the conclusions, suggestions and limitations of this paper.

2. Literature Review

2.1. The Advantages and Dilemmas of Cross-Department Data Sharing

Achieving openness and the sharing of data are the basis for efficient, agile and intelligent collaboration to deal with complex social issues in the current era of digital governance [10]. Government data sharing includes two meanings: that government departments seek data sharing from other government departments due to the need to perform their duties, and that government department data are open for sharing with the public. The cross-department data sharing studied in this paper falls under the first meaning, i.e., the act of data sharing among government departments. Data sharing requires the building of systems or platforms among different departments and the harmonization of different business data standards, as well as the transformation of business processes to meet access to data sharing [11]. Unlike the traditional hierarchy of departments, cross-department data sharing can break down the information barriers among the different departments and can improve the efficiency of the information transfer, policy coordination and public service provision within the government. In the current era of data explosion, the information resources of government departments are also growing at an explosive pace. How to achieve coordination and stability in sharing data across departments has become the key to enhancing the government's digital governance capabilities. A wealth of experience emerges from China's digital government reforms. By analyzing the "Visit Once" reform in Zhejiang, some scholars found that enhancing data sharing among departments can reconcile the contradiction between the fragmentation of administrative functions and the integration of public services, and it can improve the level of business collaboration among government departments [12]. Through the use of information technology to promote data storage in the cloud and the syncing of government services, this new type of administrative approval has achieved a change in governance by allowing data transmission instead of the masses seeking out different departments [13].

The government can improve the refinement and integration of its public services by improving the level of cross-department data sharing. On the one hand, cross-department data sharing within the government can enhance the accuracy of matching government public service supply with public demand. Cross-department data sharing has resulted in interdepartmental collaboration and functional integration, enhancing the government's ability to respond quickly and accurately to citizens' needs for governance [14,15]. On the other hand, data sharing can enable business integration and even parallel reinvention among different departments, enhancing the integration of government public services and reducing repetitive rule-based labor [16–18]. However, for a long time, the reality of inadequate government data sharing, such as "data chimneys", "data silos", and "data barriers", has always hindered cross-department business collaboration [19]. There are natural barriers to data sharing across sectors, industries, and hierarchies. The perception of data varies among different government departments, as does the perception of sectoral interests involving data. In addition, factors such as technical compatibility, the nonuniformity of the data structure, specialized operations and data security hinder the flow of data among government departments. The compartmentalization and weak correlation among business units also constrain the willingness of some departments to share data. In general, it can be simply summarized as technical factors, business factors, conceptual factors and management factors [20,21]. These problems arise due to the presence of a combination of factors, such as data-sharing inputs, data-sharing systems and unfavorable cross-department coordination [22]. Therefore, in further research, it is necessary to deeply explore the influence and effect of different factors on different subjects in the process of cross-department data sharing to provide theoretical support for analysis and to propose solutions.

2.2. Factors Influencing Cross-Department Data Sharing

In order to promote cross-department data sharing within the government, scholars from different disciplinary backgrounds have researched the issue of cross-department government data from different disciplinary paradigms, with two main disciplinary subdisciplines in general: public administration and intelligence [23,24]. Public administration scholars are more likely to study the data sharing mechanism based on government subjects and to focus on collaborative management among government departments from the organizational dimension. Cross-department data sharing needs to break down traditional administrative compartmentalization through building mechanisms [25]. A lack of trust among government departments is the cause of inactive data sharing [26]. This requires the development of appropriate systems to enhance positive incentives for cross-department data sharing, such as reward and punishment mechanisms. In the case of low levels of intersubjective trust and cooperation, top-down promotion by the central government is required [27]. The complex leadership mechanism of the "line-block structure" makes it difficult to form a centralized and unified operational mechanism and data interfacing model, resulting in "data chimneys" that are still standing [28]. The establishment of a dedicated big data management agency could be a good way to address this issue. This requires further realignment of the responsibilities and competencies to facilitate effective cross-department collaboration through the operation of a professional digital agency [21]. The study of intelligence is based on data as intelligence and focuses more on the technical aspects of government data platform construction, data sharing processes and the integration of data elements. From the perspective of the subject, enhanced training in data collection and processing, data infrastructure maintenance, and development can improve the technical capacity and digital literacy of government personnel. The cost of inhibiting government willingness to share can be reduced by harmonizing data interfaces, developing sharing specifications, and streamlining the data-sharing process. From a technical perspective, a citizen-centric model of distributed data sharing has been proposed. Distributed document exchange networks offer advantages, such as security, transparency, cost effectiveness and trust, which can better improve administrative efficiency and reduce bureaucratic procedures [29]. Some scholars have also proposed embedding blockchain technology into cross-department data governance by leveraging the decentralized and de-trusting features of blockchain technology, thereby improving the security and reliability of cross-department data sharing [30,31].

2.3. Stochastic Evolutionary Game Model

Evolutionary game theory (EGT) is a living and expanding theory that has been used in a variety of fields. EGT uses replication dynamic equations to portray the dynamic adjustment process of multi-actor strategies over time. It is widely used in supply chain finance [32], collaborative environmental management [33], drug quality regulation [34], cross-regional emergency response [35] and other scenario problems involving multisectoral cooperation. Numerical simulations have better explanatory power and degrees of perception for analyzing the dynamic change process of a strategy. Traditional EGT simulates the subject game process in a deterministic environment. However, the complex reality of society is full of randomness, uncertainty and nonlinearity, which can also have a significant impact on the subject's game. It is therefore necessary to introduce stochastic perturbations into the model to simulate complex game scenarios. The stochastic evolutionary game model (SEGM) introduces stochastic process theory to improve EGT. Shan et al. used the SEGM approach to study the collaborative management of urban public crises in complex systems, exploring how to build stable governance coalitions among local governments, enterprises and the public [36]. Li et al. took the enclave park as an example to study cross-regional collaborative governance in the process of pollution industry transfer [37]. Xu and Yang adopted the SEGM approach to study the dilemma of promoting circular logistics packaging in China [38]. In terms of the research on cross-department data sharing, researchers have focused on different perspectives, such as operational mechanisms, incentives and technological innovations. These studies have implications for this paper's further exploration of the different influences on multisubject participation in cross-department data sharing.

In summary, scholars from different disciplinary backgrounds have made some achievements on the factors influencing cross-department data sharing. In the current context of digital government construction, cross-department data sharing is a vibrant research topic. Studying the advantages and dilemmas of cross-sector data sharing requires not only theoretical analysis, but also, and more importantly, in-depth discussion in the context of some exploratory practical initiatives in the real world, such as the creation of official positions such as "Chief Data Officer" in some Chinese provinces. The practice of building digital governments is likely to be already ahead of theoretical research, so this calls for scholars to collect more characteristic initiatives from different regions for comparative studies. This paper follows this line of thought and analyzes two institutional designs with Chinese characteristics (the coordination mechanism of government data sharing and the "good and dad reviews" system). Second, whether analyzed from the organizational or technical perspective, most existing studies have been conducted from the perspective of the digital transformation of functional departments, and few studies have focused on the relationship between data management departments and functional departments. Interagency relations have always been an inseparable topic of research in the field of administration, and this is also true in the direction of digital government. Moreover, we found that previous related studies are characterized by empirical summaries and qualitative analyses, with more theoretical preconceptions and frameworks but fewer quantitative analyses. From our analysis and a summary of previous studies, it appears that cross-department data sharing is a complex and dynamic game process involving multidepartment and multisubject collaborative actions, and individual behavioral disturbances may have an impact on the overall evolutionary trend of the cross-department data sharing system. Therefore, this paper focuses on the game behavior of data management departments and the different government functional departments that are involved in data sharing, and it constructs a tripartite stochastic evolutionary game model. We explored the behavioral evolution of the three strategic subjects under the influence of different factors and the steady-state conditions of the system to propose corresponding countermeasures in conjunction with a simulation analysis, with the view of providing a theoretical reference for promoting cross-department data sharing in the government.

3. Construction of an Evolutionary Game Model for Cross-Department Data Sharing

3.1. Underlying Assumptions of the Study

Assumption 1. *The limited rationality of the subject. In the process of building a digital government, data management departments and different government functional departments are both limitedly rational in the data sharing game.*

Assumption 2. *Behavioral strategies. The data management department is responsible for coordinating the functional departments in cross-department data sharing to pool data for the digital government platform in accordance with the regulations on data collection and use, as well as for evaluating and assessing the cross-department data sharing work. Therefore, the strategy set for the data management department is {diligent management, nondiligent management} with a probability of* $(z, 1 - z)$. *The strategy set for government functional department 1 and government functional department 2 is {active sharing, negative sharing}, with probabilities of* $(x, 1 - x)$ *and* $(y, 1 - y)$. *Here,* $x, y, z \in [0, 1]$.

Assumption 3. *Data sharing costs. Government functional departments need to build and maintain departmental data information repositories based on their business and functions when sharing data across departments, paying data sharing costs* m_i $(i = 1, 2)$. *The cost of sharing is influenced by the intensity of the government's data sharing input* α. *As* α *increases, government functional departments' data sharing input also increase. Thus, the cost of data sharing for government functions under a negative sharing strategy is* αm_i.

Assumption 4. *Data sharing benefits. The potential for effective cross-department data sharing is to deliver the expected benefits in terms of improved administrative efficiency, streamlined business processes, enhanced capacity of government departments and reduced costs of government services [39]. A lack of awareness of the benefits of data sharing was cited as the main reason for the level of sectoral participation in data sharing. Moreover, the nonexclusive nature of shared data as a public good leads to spillover benefits from data sharing, specifically in the form of synergistic benefits for nonpartners. Therefore, considering that data sharing benefits are closely related to the data from other departments, cross-department data sharing benefits* Q_i $(i = 1, 2)$ *and the data sharing synergy benefits coefficient* β $(0 \leq \beta \leq 1)$ *are assumed for government functions. When a government functional department chooses a negative strategy, it still gains some of the synergy* *benefits because of the positive sharing by other departments. The data management department can achieve departmental performance gains P based on the results of data sharing across government functional departments. When all government functional departments adopt the active strategy, the data management department performance gains are similarly influenced by the level of cross-sector collaboration as (1 +* β*) P. Of course, the p-value for the case in which neither department shares is zero.*

Assumption 5. *Digital literacy. Digital literacy is seen as the data absorptive capacity of civil servants as manifested in the digital transformation of the government, highlighted by the data identification capacity, data verification capacity and data utilization capacity of the departmental staff [28]. Active participation in data sharing can enhance the digital literacy of government staff. The active participation of government functional departments can enhance the digital literacy of government staff, which is expressed in the benefit matrix as an offset to the cost of departmental data sharing. In addition, the data management department, as the lead department for digital government construction and the competent department for the development and use of public data resources, is able to organize resources from the community and universities to conduct training on digital topics and to improve the digital literacy of government staff [40]. Based on the above analysis, this article assumes that the digital literacy stock of government functional departments is* L_i *(i = 1, 2). It costs n for data management to organize training on digital topics, and the training intensity coefficient is* μ *(*$0 \leq \mu \leq 1$*). In the case of due diligence management, the data management department organizes digital training with an intensity of 1, and the cost of digital training without a due diligence management strategy is* μn*. Furthermore, digital literacy in government functional departments grows to* $(1 + \mu)L_i$ *with the data management department's training.*

Assumption 6. *Expected losses and interagency trust. The expected loss is a nontechnical factor that affects the success of cross-department data sharing and represents a hidden concern among government departments regarding the potential loss to the department from cross-department data sharing. Expected losses include the three main risks of the misuse and abuse of shared data, exposure of sensitive data and derogation of sectoral power due to the fact of proprietary data sharing [39,41]. In particular, public departments such as the Public Security Bureau, the Civil Affairs Bureau and the Health Security Bureau, which have large amounts of private information concering citizens, have more significant concerns about expected losses in participating in cross-department data sharing. A study of the National Spatial Data Infrastructure (NSDI) in the United States found that most government departments tend to open up lower levels of data access rather than providing free access without a threshold as a way to reduce the risk of potential liability lawsuits against the department [42]. At the actor level, government departments' concerns about expected losses from data sharing are often associated with interagency trust, as captured in Yang and Maxwell's comprehensive model [26]. Cross-sectoral information sharing can mitigate concerns about expected losses by increasing trust among participants [43–45]. In this regard, the Chinese government has exploratively established a coordination mechanism for government data sharing that can both enhance the data management authority of data management departments and increase the level of interagency collaboration and trust among governmental functional departments [46]. In this paper, we assumed that the expected loss of government functional departments for cross-sector data sharing is* F_i *(i = 1, 2) and that the interagency trust stock is T. An effective coordination mechanism for government data sharing is established when data management departments manage with due diligence, and the effect coefficient of the coordination mechanism for government data sharing is* θ*. The coordination mechanism for government data sharing enables the data management department to gain data management authority gains G. The mechanism does not work when the data management department does not manage with due diligence but still obtains data management authority gains G in the case of government functional departments choosing to actively share. The expected loss of government functional departments under interagency trust regulation is denoted as* $(1 - \theta + 1/T)F_i$*, the expected loss in the presence of a party not actively sharing is denoted as* $(1 - \theta)F_i$*, and the gain in the authority of the data management department is* $(1 + \theta)G$ *[40,46].*

Assumption 7. *"Good and bad reviews" system. One practical initiative of the Chinese government in the process of digital government construction is the evaluation of the level of government services* *through the public. The data management department organizes the construction of the "good and bad reviews" management system, in which citizens evaluate the level of the government services of government functional departments, and the evaluation results make government departments receive awards or urge rectification. This study assumes that the "good and bad reviews" system construction effort coefficient is λ, that the data management department organizes and builds the "good and bad reviews" management system at a cost of C and that the system construction is rewarded by the superior department at a benefit of K. When both government functional departments are active in data sharing, both are equally recognized and rewarded by higher authorities with K. Government functional departments that are not actively shared can affect the efficiency of their government services. They are monitored and punished by higher authorities focused on R due to the fact of bad reviews, which are all regulated by the system construction effort λ.*

The parameter settings of the interdepartmental data sharing model and its symbolic expressions in this paper are shown in Table 1.

Table 1. Parameter settings and their symbols.

Parameter	Symbol	Description
Data sharing costs of government functional departments	m_i	$m_i > 0, i = 1, 2$
Data sharing input intensity of government functional departments	α	$0 \leq \alpha \leq 1$
Cross-department data sharing benefits of government functional departments	Q_i	$Q_i > 0, i = 1, 2$
Data sharing synergy benefits coefficient of government functional departments	β	$0 \leq \beta \leq 1$
Performance gains for the data management department from data sharing	P	$P \geq 0$
Digital literacy stock of government functional departments	L_i	$L_i > 0, i = 1, 2$
Cost of the digital thematic training organized by the data management department	n	$n > 0$
Training intensity coefficient of the digital thematic training organized by the data management department	μ	$0 \leq \mu \leq 1$
Expected loss of cross-department data sharing of government functional departments	F_i	$F_i > 0, i = 1, 2$
Interagency trust stock of government functional departments	T	$T > 0$
Effect coefficient of the coordination mechanism for government data sharing	θ	$0 \leq \theta \leq 1$
Data management authority gains of the data management department	G	$G > 0$
Cost of building the "good and bad reviews" system for the data management department	C	$C > 0$
Construction effort coefficient of the "good and bad reviews" system	λ	$0 \leq \lambda \leq 1$
Rewards from higher authorities from the "good and bad reviews" system's construction	K	$K > 0$
Evaluation loss of the government functional departments due to the fact of bad reviews	R	$R > 0$

3.2. Payoff Matrix and Game Model Construction

Based on the above assumptions and parameter settings, the tripartite payoff matrix constructed in this paper is shown in Table 2 in order to further analyze the gains and losses of the game between the data management department and the government functional departments. In the table, diligent management (Dm) and nondiligent management (Nm) are the two strategies for the data management department; active sharing (As_1) and negative sharing (Ns_1) represent the two types of choices for government functional department 1; and active sharing (As_2) and negative sharing (Ns_2) belong to government functional department 2.

Table 2. The payoff matrix of the data management department and different functional departments.

Strategy	Government Functional Department 1	Government Functional Department 2	Data Management Department
(As_1, As_2, Dm)	$-m_1 + Q_1 + \beta Q_2 + 2L_1 - (1 - \theta + \frac{1}{T})F_1 + K$	$-m_2 + Q_2 + \beta Q_1 + 2L_2 - (1 - \theta + \frac{1}{T})F_2 + K$	$(1+\beta)P - n + (1+\theta)G + (K - C)$
(As_1, Ns_2, Dm)	$-m_1 + Q_1 + 2L_1 - (1-\theta)F_1 - R$	$-\alpha m_2 + \beta Q_1 + 2L_2 - (1-\theta)F_2 - R$	$P - n + (1+\theta)G + (K - C)$
(As_1, As_2, Nm)	$-m_1 + Q_1 + \beta Q_2 + (1+\mu)L_1 - (1 + \frac{1}{T})F_1 + \lambda K$	$-m_2 + Q_2 + \beta Q_1 + (1+\mu)L_2 - (1 + \frac{1}{T})F_2 + \lambda K$	$(1+\beta)P - \mu n + G + \lambda(K - C)$
(As_1, Ns_2, Nm)	$-m_1 + Q_1 + (1+\mu)L_1 - F_1 - \lambda R$	$-\alpha m_2 + \beta Q_1 + (1+\mu)L_2 - F_2 - \lambda R$	$P - \mu n + G + \lambda(K - C)$
(Ns_1, As_2, Dm)	$-\alpha m_1 + \beta Q_2 + 2L_1 - (1-\theta)F_1 - R$	$-m_2 + Q_2 + 2L_2 - (1-\theta)F_2 - R$	$P - n + (1+\theta)G + (K - C)$
(Ns_1, Ns_2, Dm)	$-\alpha m_1 + 2L_1 - (1-\theta)F_1 - R$	$-\alpha m_2 + 2L_2 - (1-\theta)F_2 - R$	$-n + (K - C)$
(Ns_1, As_2, Nm)	$-\alpha m_1 + \beta Q_1 + (1+\mu)L_1 - F_1 - \lambda R$	$-m_2 + Q_2 + (1+\mu)L_2 - F_2 - \lambda R$	$P - \mu n + G + \lambda(K - C)$
(Ns_1, Ns_2, Nm)	$-\alpha m_1 + (1+\mu)L_1 - F_1 - \lambda R$	$-\alpha m_2 + (1+\mu)L_2 - F_2 - \lambda R$	$-\mu n + \lambda(K - C)$

Individuals in EGT adjust their own strategies by imitating the strategies of other individuals, i.e., by replicating the dynamic update rule. We constructed the replication dynamic equations for the three subjects based on the payoff matrix.

The expected benefits of choosing an active strategy for government functional department 1, government functional department 2 and the data management department are

$$\begin{aligned} U_{11} = {} & yz\left[-m_1 + Q_1 + \beta Q_2 + 2L_1 - \left(1 - \theta + \tfrac{1}{T}\right)F_1 + K\right] + y(1-z)\left[-m_1 + Q_1 + \beta Q_2 + (1+\mu)L_1 - \left(1 + \tfrac{1}{T}\right)F_1 + \lambda K\right] \\ & + z(1-y)[-m_1 + Q_1 + 2L_1 - (1-\theta)F_1 - R] + (1-y)(1-z)[-m_1 + Q_1 + (1+\mu)L_1 - F_1 - \lambda R] \end{aligned} \tag{1}$$

$$\begin{aligned} U_{21} = {} & xz\left[-m_2 + Q_2 + \beta Q_1 + 2L_2 - \left(1 - \theta + \tfrac{1}{T}\right)F_2 + K\right] + x(1-z)\left[-m_2 + Q_2 + \beta Q_1 + (1+\mu)L_2 - \left(1 + \tfrac{1}{T}\right)F_2 + \lambda K\right] \\ & + z(1-x)[-m_2 + Q_2 + 2L_2 - (1-\theta)F_2 - R] + (1-x)(1-z)[-m_2 + Q_2 + (1+\mu)L_2 - F_2 - \lambda R] \end{aligned} \tag{2}$$

$$\begin{aligned} U_{31} = {} & xy[(1+\beta)P - n + (1+\theta)G + (K - C)] + x(1-y)[P - n + (1+\theta)G + (K - C)] \\ & + y(1-x)[P - n + (1+\theta)G + (K - C)] + (1-x)(1-y)[-n + (K - C)] \end{aligned} \tag{3}$$

The expected benefits of choosing a negative strategy for government functional department 1, government functional department 2 and the data management department are

$$\begin{aligned} U_{12} = {} & yz[-\alpha m_1 + \beta Q_2 + 2L_1 - (1-\theta)F_1 - R] + y(1-z)[-\alpha m_1 + \beta Q_1 + (1+\mu)L_1 - F_1 - \lambda R] \\ & + z(1-y)[-\alpha m_1 + 2L_1 - (1-\theta)F_1 - R] + (1-y)(1-z)[-\alpha m_1 + (1+\mu)L_1 - F_1 - \lambda R] \end{aligned} \tag{4}$$

$$\begin{aligned} U_{22} = {} & xz[-\alpha m_2 + \beta Q_1 + 2L_2 - (1-\theta)F_2 - R] + x(1-z)[-\alpha m_2 + \beta Q_1 + (1+\mu)L_2 - F_2 - \lambda R] \\ & + z(1-x)[-\alpha m_2 + 2L_2 - (1-\theta)F_2 - R] + (1-x)(1-z)[-\alpha m_2 + (1+\mu)L_2 - F_2 - \lambda R] \end{aligned} \tag{5}$$

$$\begin{aligned} U_{32} = {} & xy[(1+\beta)P - \mu n + G + \lambda(K - C)] + x(1-y)[P - \mu n + G + \lambda(K - C)] \\ & + y(1-x)[P - \mu n + G + \lambda(K - C)] + (1-x)(1-y)[-\mu n + \lambda(K - C)] \end{aligned} \tag{6}$$

The average expected benefits for government functional department 1, government functional department 2, and the data management department are

$$\overline{U_1} = xU_{11} + (1-x)U_{12} \tag{7}$$

$$\overline{U_2} = yU_{21} + (1-y)U_{22} \tag{8}$$

$$\overline{U_3} = zU_{31} + (1-z)U_{32} \tag{9}$$

Based on the calculations of Equations (7)–(9), we obtained the replication dynamics equations for government functional department 1, government functional department 2 and the data management department:

$$\begin{aligned} A(x) &= \tfrac{dx}{dt} = x\left(U_{11} - \overline{U_1}\right) = x(1-x)(U_{11} - U_{12}) \\ &= x(1-x)\left\{yz[\beta Q_1 - Q_2 + (1-\lambda)(K+R)] + y\left[-\beta Q_1 + Q_2 - \tfrac{1}{T}F_1 + \lambda(K+R)\right] + (\alpha-1)m_1 + Q_1\right\} \end{aligned} \tag{10}$$

$$\begin{aligned} B(y) &= \tfrac{dy}{dt} = y\left(U_{21} - \overline{U_2}\right) = y(1-y)(U_{21} - U_{22}) \\ &= y(1-y)\left\{xz(1-\lambda)(K+R) + x\left[-\tfrac{1}{T}F_2 + \lambda(K+R)\right] + (\alpha-1)m_2 + Q_2\right\} \end{aligned} \tag{11}$$

$$H(z) = \frac{dz}{dt} = z\left(U_{31} - \overline{U_3}\right) = z(1-z)(U_{31} - U_{32}) = z(1-z)[(x+y-xy)\theta G + (\mu-1)n + (1-\lambda)(K-C)] \tag{12}$$

Because $x, y, z \in [0,1]$, it is known that $1-x$, $1-y$ and $1-z$ are non-negative, which has no effect on the strategy results of the game model. Therefore, the replication dynamics equations of the above three subjects are integrated to improve the replication dynamics system of the tripartite game of cross-department data sharing in this paper, as shown below:

$$\begin{cases} A(x) = x\left\{yz[\beta Q_1 - Q_2 + (1-\lambda)(K+R)] + y\left[-\beta Q_1 + Q_2 - \tfrac{1}{T}F_1 + \lambda(K+R)\right] + (\alpha-1)m_1 + Q_1\right\} \\ B(y) = y\left\{xz(1-\lambda)(K+R) + x\left[-\tfrac{1}{T}F_2 + \lambda(K+R)\right] + (\alpha-1)m_2 + Q_2\right\} \\ H(z) = z[(x+y-xy)\theta G + (\mu-1)n + (1-\lambda)(K-C)] \end{cases} \tag{13}$$

4. Construction of the Stochastic Evolutionary Game Model for Cross-Department Data Sharing

4.1. Introducing White Gaussian Noise into the Model

In order to better model the complex real-world environment in which cross-sector data sharing occurs, we introduced white Gaussian noise as a random perturbation and improved the tripartite model (13) of EGT. The set of Equation (14) shows the stochastic evolutionary game model for cross-department data sharing:

$$\begin{cases} dx(t) = \left\{yz[\beta Q_1 - Q_2 + (1-\lambda)(K+R)] + y\left[-\beta Q_1 + Q_2 - \tfrac{1}{T}F_1 + \lambda(K+R)\right] + (\alpha-1)m_1 + Q_1\right\}x(t)dt + \sigma x(t)d\omega(t) \\ dy(t) = \left\{xz(1-\lambda)(K+R) + x\left[-\tfrac{1}{T}F_2 + \lambda(K+R)\right] + (\alpha-1)m_2 + Q_2\right\}y(t)dt + \sigma y(t)d\omega(t) \\ dz(t) = [(x+y-xy)\theta G + (\mu-1)n + (1-\lambda)(K-C)]z(t)dt + \sigma z(t)d\omega(t) \end{cases} \tag{14}$$

This game system is a nonlinear *Itô* system of stochastic differential equations, in which $\omega(t)$ is the one-dimensional standard Brown motion. Brown motion is an irregular motion with a stochastic phenomenon, so it can effectively describe the interference of cross-department data sharing by stochastic factors. $\Delta\omega(t) = [\omega(t+h) - \omega(t)] \sim N(0, \sqrt{h})$, the step size is $h > 0$, and $d\omega(t)$ is white Gaussian noise. $\sigma x(t)d\omega(t), \sigma y(t)d\omega(t), \sigma z(t)d\omega(t)$ are the random disturbance terms for each subsystem of the game model, respectively, where σ denotes the disturbance intensity and $\sigma x(t) = \sqrt{x(t)(1-x(t))}$, $\sigma y(t) = \sqrt{y(t)(1-y(t))}$ and $\sigma z(t) = \sqrt{z(t)(1-z(t))}$. The random perturbation reaches its maximum when and only when $x = y = z = 0.5$. This phenomenon is more in line with the reality of performance. In group decision making, subjects prefer a decision with high probability and a large proportion of choosers due to the fact of the herding effect. However, when the probabilities of the two strategies are similar, the subject's decision is more likely to be influenced by external disturbing factors.

4.2. Analysis of the Existence and Stability of the Equilibrium Solution of the Model

First, we considered the zero solution case. For the stochastic evolutionary game system (14), we analyzed the initial moment $t = 0$ of the tripartite game. By letting $x(0) = y(0) = z(0) = 0$, it can obviously be seen that

$$\begin{cases} \left\{yz[\beta Q_1 - Q_2 + (1-\lambda)(K+R)] + y\left[-\beta Q_1 + Q_2 - \frac{1}{T}F_1 + \lambda(K+R)\right] + (\alpha-1)m_1 + Q_1\right\} \times 0 + 0 \times d\omega(t) = 0 \\ \left\{xz(1-\lambda)(K+R) + x\left[-\frac{1}{T}F_2 + \lambda(K+R)\right] + (\alpha-1)m_2 + Q_2\right\} \times 0 + 0 \times d\omega(t) = 0 \\ [(x+y-xy)\theta G + (\mu-1)n + (1-\lambda)(K-C)] \times 0 + 0 \times d\omega(t) = 0 \end{cases} \quad (15)$$

From the system of Equation (15), we can see that the dynamic system is always stable in the zero solution state without white noise interference, and the zero solution is the equilibrium solution of the equations. This implies that there is a starting point for data sharing actions that are followed by each subject without initial interference from unpredictable external factors, such as collaboration risks and transaction costs. However, this unperturbed situation does not exist in reality. Furthermore, according to the stability discriminant theorem for stochastic differential equations, we considered the effect of stochastic disturbances on the stability of the evolutionary game system. Consider a given stochastic differential equation:

$$dx(t) = f(t, x(t))dt + g(t, x(t))d\omega(t), x(t_0) = x_0$$

Let there exist a continuous differentiable function $V(t, x)$ and positive constants c_1 and c_2, such that $c_1|x|_p \leq V(t, x) \leq c_2|x|^p$, $t \geq 0$. If there exists a positive constant number γ such that $LV(t, x) \geq \gamma V(t, x)$, then the zero solution of this stochastic differential equation of p-order is exponentially stable, and it holds that $E|x(t, x_0)|_p < (c_2/c_1)|x_0|_p e^{-\gamma t}, t \geq 0$.

Regarding the system of Equation (14), by taking $V_t(t, x) = x, V_t(t, y) = y$, $V_t(t, z) = z, x, y, z \in [0, 1]$, $c_1 = c_2 = 1$, $p = 1$ and $\gamma = 1$, we can obtain the following equations:

$$LV(t,x) = f(t,x) = x\left\{yz[\beta Q_1 - Q_2 + (1-\lambda)(K+R)] + y\left[-\beta Q_1 + Q_2 - \frac{1}{T}F_1 + \lambda(K+R)\right] + (\alpha-1)m_1 + Q_1\right\}$$

$$LV(t,y) = f(t,y) = y\left\{xz(1-\lambda)(K+R) + x\left[-\frac{1}{T}F_2 + \lambda(K+R)\right] + (\alpha-1)m_2 + Q_2\right\}$$

$$LV(t,z) = f(t,z) = z[(x+y-xy)\theta G + (\mu-1)n + (1-\lambda)(K-C)]$$

For the zero solution moments of the stochastic differential equation to be exponentially stable, the following conditions need to be satisfied:

$$x\left\{yz[\beta Q_1 - Q_2 + (1-\lambda)(K+R)] + y\left[-\beta Q_1 + Q_2 - \frac{1}{T}F_1 + \lambda(K+R)\right] + (\alpha-1)m_1 + Q_1\right\} \leq -x \quad (16)$$

$$y\left\{xz(1-\lambda)(K+R) + x\left[-\frac{1}{T}F_2 + \lambda(K+R)\right] + (\alpha-1)m_2 + Q_2\right\} \leq -y \quad (17)$$

$$z[(x+y-xy)\theta G + (\mu-1)n + (1-\lambda)(K-C)] \leq -z \quad (18)$$

4.3. Taylor Expansion of the Evolution Equation

Because the equations in the system (14) are nonlinear *Itô* stochastic differential equations, there is no need to solve them analytically, and they can be solved using a stochastic Taylor expansion. The form of the explicit forward Euler method is $x_{n+1} = x_n + hf(x_n) + \Delta\omega_n g(x_n)$.

We expanded the equations in the stochastic game system (14) according to this format to obtain Equations (16)–(18).

$$x_{n+1} = x_n + x\left\{yz[\beta Q_1 - Q_2 + (1-\lambda)(K+R)] + y\left[-\beta Q_1 + Q_2 - \frac{1}{T}F_1 + \lambda(K+R)\right] + (\alpha-1)m_1 + Q_1\right\}h + \Delta\omega_n \sigma x(n) \tag{19}$$

$$y_{n+1} = y_n + y\left\{xz(1-\lambda)(K+R) + x\left[-\frac{1}{T}F_2 + \lambda(K+R)\right] + (\alpha-1)m_2 + Q_2\right\}h + \Delta\omega_n \sigma y(n) \tag{20}$$

$$z_{n+1} = z_n + z[(x+y-xy)\theta G + (\mu-1)n + (1-\lambda)(K-C)]h + \Delta\omega_n \sigma z(n) \tag{21}$$

5. Simulation Analysis of a Stochastic Evolutionary Game of Cross-Department Data Sharing

We carried out numerical simulations based on the set of Equations (19)–(21) expanded by the explicit forward Euler method, which allowed us to observe the whole game evolution process more clearly and intuitively to explore in-depth the mechanism of the influence of different game factors of the data management department and the government functional departments on the overall evolution of the game system.

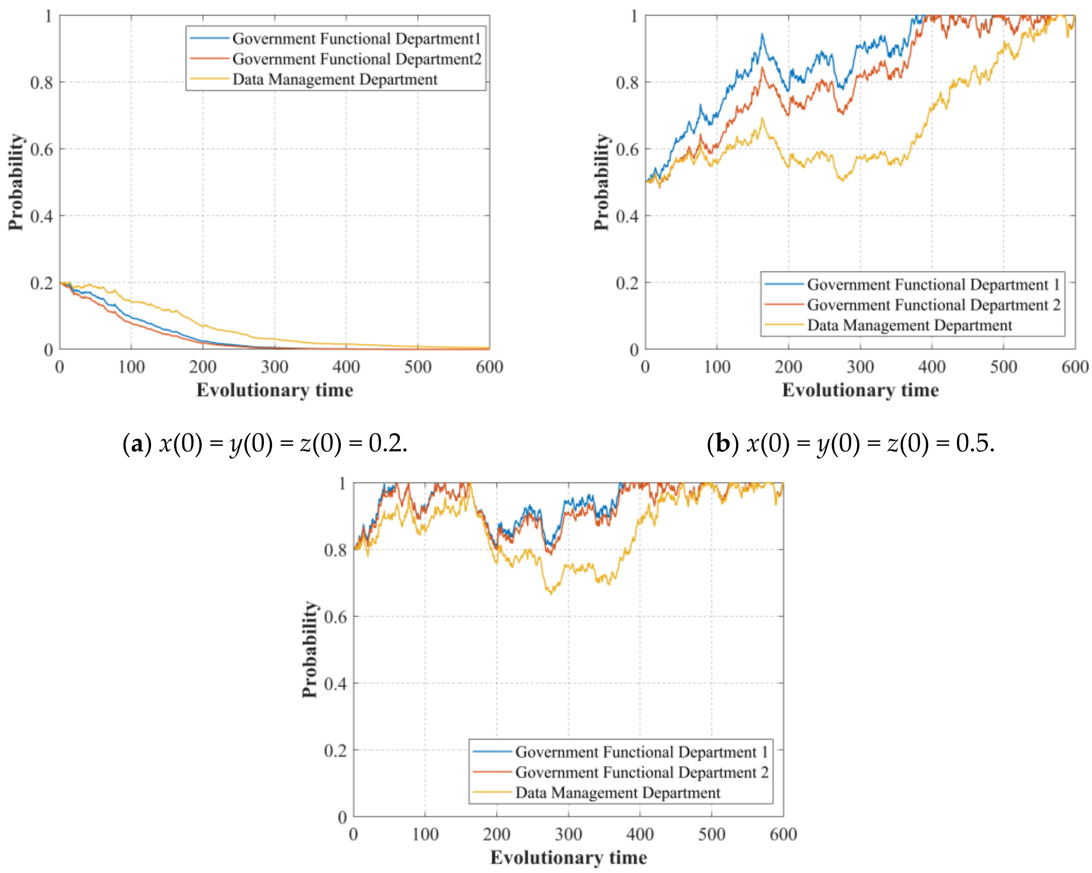
5.1. Simulation Analysis of the Effects of the Initial Probability on the Stochastic Game System

Because the real data set is large and difficult to obtain and process, we randomly set the data that are used in the numerical examples according to the conditions in Equations (16)–(18). This has no practical significance, to some extent, but has some theoretical value. The simulation data are set as follows:

m1 = 95, m2 = 105, α = 0.5, Q1 = 30, Q2 = 35, β = 0.3, n = 10, μ = 0.5, F1 = 60, F2 = 75, T = 10, θ = 0.5, G = 28, C = 20, λ = 0.5, K = 12, R = 45, P = 40, L1 = 12, and L2 = 10.

The initial probability reflects the initial willingness level of the data management department and the different government functional departments to participate in cross-sector data sharing. In this paper, we first considered the behavioral evolution process of the game system under different initial willingness strengths of the three subjects. We set $x(0) = y(0) = z(0) = 0.2$, 0.5 and 0.8, and the simulation results are shown in Figure 1.

In the final results of our initial probability simulation, it can be seen that the initial willingness of each subject to participate in cross-department data sharing has a significant impact on the steady state of the overall data sharing system. At the initial time when the initial willingness of each subject is at a low value ($x(0) = y(0) = z(0) = 0.2$), there is a tendency for the probability of sharing to increase among the three subjects after a period of exploration and friction. The game system eventually stabilizes at (0, 0, 0), which means that the evolution of the three subjects tends to be all uncooperative and fall into the dilemma of the public goods game. However, as we raise the initial probability ($x(0) = y(0) = z(0) = 0.5$), the government functional departments choose to actively share by comparing data sharing costs, expected losses and data sharing benefits, driven by the net data sharing benefits. Even though the net benefits of due diligence management are not high, the data management department chooses to conduct its due diligence because of the additional data management authority benefits of the government data sharing and coordination mechanism. In a stochastic interference environment, it is clearly evident that the strategies of both the data management department and the government functional departments show fluctuations and instability. After a certain amount of time of the gaming process, a relatively stable strategy state would eventually be reached. Initial willingness can significantly affect the rate at which steady states are reached. When all three subjects are at a low initial willingness, there is insufficient intrinsic drive for due diligence management by data management authorities. It can be seen in Figure 1a that the data management department is slower in choosing negative strategies than the government functional departments are. In Figure 1b,c, the cycle time for the data management department and the government functional department to reach a steady state is compressed, although there are fluctuations in the process. In a further analysis, we consider whether different interventions can additionally improve this process.



(**a**) $x(0) = y(0) = z(0) = 0.2$. (**b**) $x(0) = y(0) = z(0) = 0.5$.

(**c**) $x(0) = y(0) = z(0) = 0.8$.

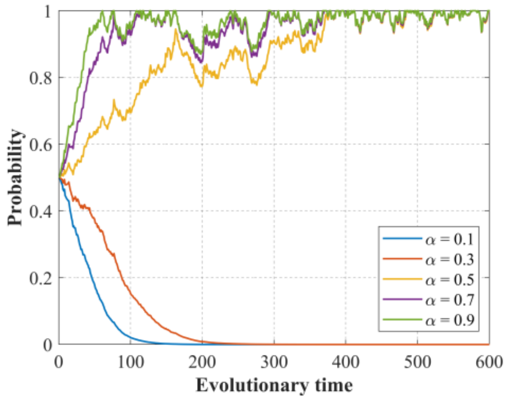
Figure 1. Stochastic game evolution for cross-department data sharing with different initial probabilities.

5.2. Simulation Analysis of the Effects of Different Variables on the Stochastic Game System

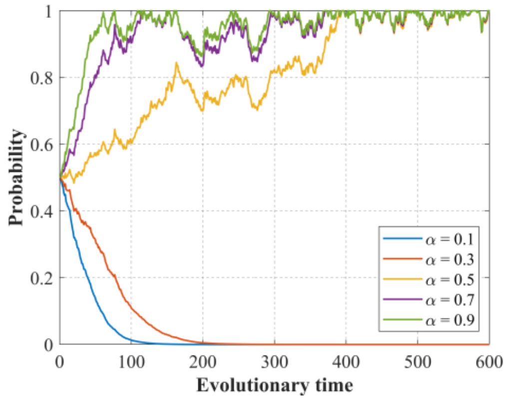
To further analyze the influence of some key parameters on the overall evolution of the stochastic game system, we still use the above values for the simulation. The initial probability of each game subject's strategy in the stochastic game system of cross-department data sharing was set to 0.5. We discuss the evolutionary process of the impact of five parameters on the game system in Sections 5.2.1–5.2.5, which discuss the data sharing input intensity of the government functional departments, the training intensity coefficient of the digital thematic training organized by the data management department, the effect coefficient of the coordination mechanism for the government data sharing, the interagency trust stock of the government functional departments and the construction effort coefficient of the "good and bad reviews" system.

5.2.1. The Impact of Parameter α on the Strategies of the Tripartite Subjects

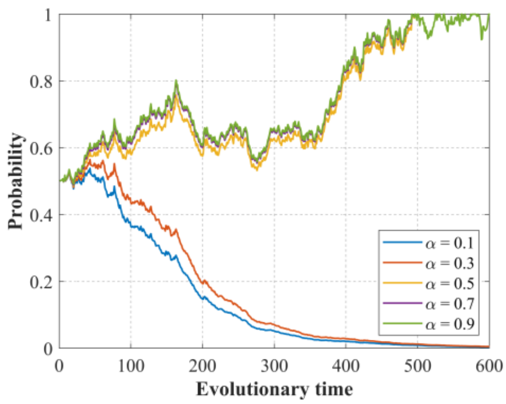
The impact of the change in the data sharing input intensity α of the government functional departments on the evolutionary path of government functional department 1, government functional department 2 and the data management department is illustrated in Figure 2a–c. Let α be 0.1, 0.3, 0.5, 0.7 and 0.9. When $\alpha = 0.1$, both the data management department and the government functional departments choose nonaggressive strategies. As the intensity of the investment in data sharing by government functions increases, the data management department shifts from nondiligent management to diligent management, and the government functional departments rapidly shift to active sharing. This is due to the fact that, as the investment in data sharing increases, the government functional departments choose to aggressively share data driven by the improved net benefits of data sharing. This means that, as the intensity of investment in data sharing among the functional departments increases, the construction of departmental data information base systems becomes increasingly perfect, and the standardization of business data is improved. Although enhanced inputs imply higher data sharing costs for government functional departments, the externality effects of data sharing under improved infrastructure conditions prompt the functional departments to choose to share actively. Under the role of the government data sharing coordination mechanism, increased data sharing input implies that departments value digitalization and actively cooperate with data management departments to promote digital government construction. Although the net benefits of data management departments are limited, data management departments tend to conduct their due diligence in guiding and managing functional departments to enhance their power attributes in the government sequence by seizing the authoritative benefits of data management.



(**a**) Government functional department 1.



(**b**) Government functional department 2.

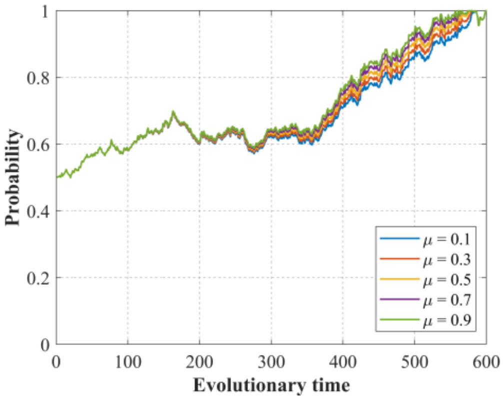


(**c**) Data management department.

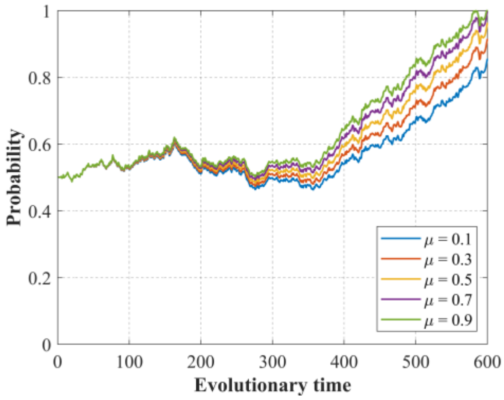
Figure 2. Influence of the data sharing input intensity α of the government functional departments on the evolutionary paths of the tripartite subjects.

5.2.2. The Impact of Parameter μ on the Strategies of Tripartite Subjects

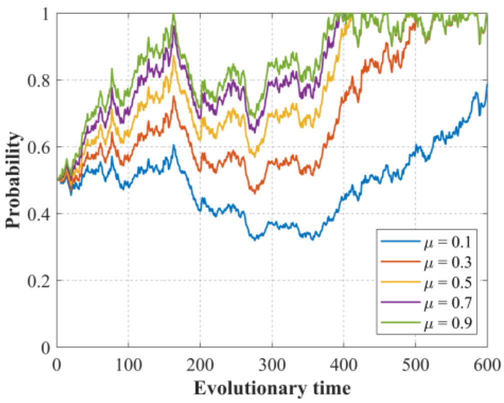
The impact of the change in the training intensity coefficient of the digital thematic training organized by the data management department on the evolutionary path of government functional department 1, government functional department 2 and the data management department is illustrated in Figure 3a–c. The data management department's digital training intensity coefficient μ is taken from 0.1 to 0.9, with an interval of 0.2. The figure shows that the game system eventually converges to a steady state of (1, 1, 1), regardless of the value of the digital training intensity coefficient. As the training intensity increases, the rate at which the system reaches the positive steady state gradually increases. This suggests that digital training does not change the net benefit profile of the government functional departments and the data management department and that the government functional departments continue to choose to share based on the incentive of the net benefits of data sharing. However, the increased intensity of the digital training enhances the ability of the functional staff to identify, validate and use data, and the improved digital literacy of departments fundamentally reduces the cost of digital sharing and further amplifies the net benefits of data sharing, which drives functional departments to more actively choose data sharing partnerships. The increased intensity of the digital training increases the cost of operations for the data management department, but the data management department is not influenced by the net benefits in this scenario to choose a negative strategy. On the contrary, in the coordination mechanism of government data sharing, the data management department, as the leading department of digital government construction and the competent department of public data resources development and utilization, can further expand the influence ability of the data management department in the functional sectors by enhancing digital training to obtain data management authority gains. Moreover, the behavioral choice of increasing digital training on data management would imply a preference for due diligence management itself.



(**a**) Government functional department 1.



(**b**) Government functional department 2.

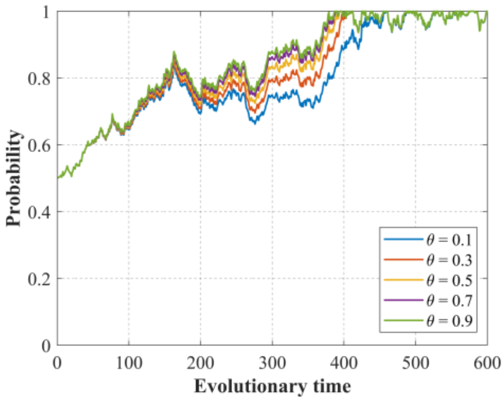


(**c**) Data management department.

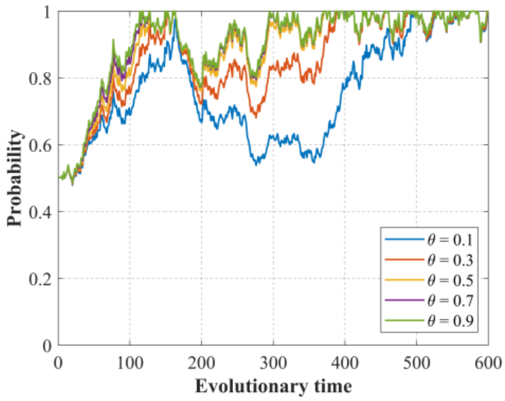
Figure 3. Influence of the training intensity coefficient μ of digital thematic training organized by the data management department on the evolutionary paths of the tripartite subjects.

5.2.3. The Impact of Parameter θ on the Strategies of the Tripartite Subjects

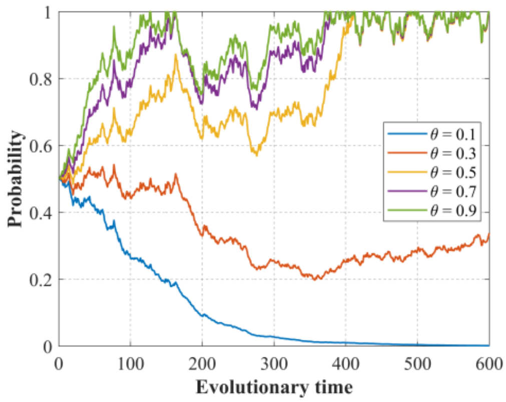
The impact of the change in the effect coefficient of the coordination mechanism for government data sharing on the evolutionary path of government functional department 1, government functional department 2 and the data management department is illustrated in Figure 4a–c. We set the government data sharing coordination mechanism effect coefficients θ to take 0.1, 0.3, 0.5, 0.7 and 0.9. This simulation process reveals a solution with Chinese characteristics to address interagency trust by building a coordination mechanism for government data sharing to coordinate interagency collective action relationships. In the simulation scenario, the government functional departments act more consistently, choosing to share actively among net benefit incentives for data sharing. However, due to differences in departmental attributes, data sharing among functional departments inevitably fluctuates, as can be seen in Figure 4a,b. When $\theta = 0.1$, the construction of a coordination mechanism for government data sharing is not yet sound, and the data management department gains less authority over data management and tends to choose not to manage with due diligence. The choice of sharing among the government functional departments also fluctuates widely, suggesting that the sharing process is iterative and a "tug of war". With the enhanced effect of the coordination mechanism for government data sharing and the soundness of the coordination mechanism for government data sharing led by the data management department, the responsibilities of the functional departments for government data sharing and the coordination of data sharing are greatly enhanced. On the one hand, the interinstitutional trust relationship capital of the functional departments is further accumulated and expanded, and their willingness to share data is further enhanced from the original basis, so the rate of choosing active sharing is significantly increased. On the other hand, the business responsibilities of the data management department in cross-department data sharing are greatly strengthened, the coordination ability of the data management department among the various departments is enhanced, the authoritative gains of the data management department are improved, and the department gradually shifts from the original non-due-diligence management to due diligence management.



(**a**) Government functional department 1.



(**b**) Government functional department 2.



(**c**) Data management department.

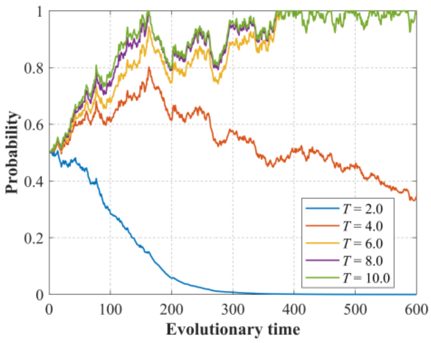
Figure 4. Influence of the effect coefficient θ of the coordination mechanism for government data sharing on the evolutionary paths of the tripartite subjects.

5.2.4. The Impact of Parameter T on the Strategies of the Tripartite Subjects

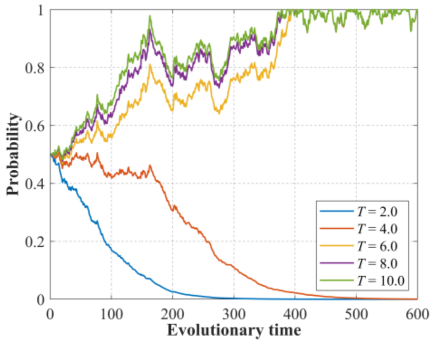
The impact of the change in the interagency trust stock of government functional departments on the evolutionary path of government functional department 1, government functional department 2 and the data management department is illustrated in Figure 5a–c. We set the parameter T separately as 2.0, 4.0, 6.0, 8.0 and 10.0. Unlike the discussion of the other coefficient parameters, the study of the stock of interinstitutional trust relationships does not reflect the effect level of the new mechanism construction on the tripartite game of cross-sector data sharing that is studied in this paper. However, the simulation is a direct reflection of the extent to which interagency cooperation affects cross-department data sharing, further validating the view of some scholars that governmental concerns about expected losses from data sharing are often associated with interagency trust [26]. The results that are presented in the simulation of the model in this paper are also more interesting. The interagency trust relationship stock characterizes the degree of closeness and trust in the prior business partnership between functional departments. The interagency trust relationship stock characterizes the degree of closeness and trust in the prior business partnership among functional departments. Unlike the consistency of functional departmental behavior in other simulations, when the stock of interagency trust relationships is at a low level, differences and disagreements can be seen among government functional departments regarding whether to actively participate in cross-department data sharing, which may result in an awkward situation in which some are actively sharing, whereas others are negatively sharing. For example, when $T = 4$, the strategy of functional department 1 has a clear positive tendency, whereas functional department 2 tends to be directly negative. As the stock of interagency trust relationships rises, departments that are negatively involved in data sharing gradually shift to active participation strategies under the due diligence management and guidance of the data management department, but this process does not happen overnight and is a gradual transformation that accompanies the accumulation of the stock of interagency trust relationships. This shows that it is also necessary to enhance the contact and cooperation of functional departments outside data sharing in order for them to cooperate in data sharing.

5.2.5. The Impact of Parameter λ on the Strategies of the Tripartite Subjects

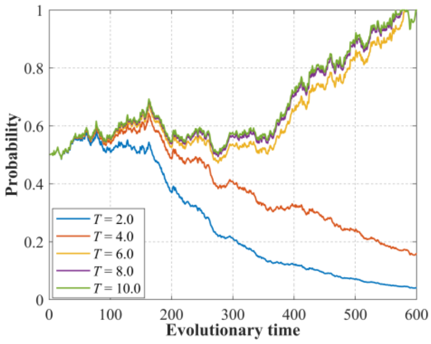
The impact of the change in the construction effort coefficient of the "good and bad reviews" system on the evolutionary path of government functional department 1, government functional department 2 and the data management department is illustrated in Figure 6a–c. We set the parameter λ separately as 0.1, 0.3, 0.5, 0.7 and 0.9. The "good and bad reviews" system is another practical initiative with Chinese characteristics in the process of digital government construction. The results are also obvious from the game relationship essentially introducing public supervision and superior rewards and punishments as compatible behavioral incentives for the game subject's strategic choices. When the construction of the "good and bad reviews" system is at a low level, the supervision mechanism is not yet perfect, and the data management department and government functional departments do not treat cross-department data sharing positively, resulting in the game system finally stabilizing at (0, 0, 0). With the strengthening of the "good and bad reviews" system, the rate at which the data management department and government functional departments choose positive strategies gradually increases. The superior's commendation and supervision are a reinforcement of the subjects' willingness to be guided further on the basis of their original behavioral choices. The recognition of the functional departments in addition to the net benefit incentive of data sharing further enhances their willingness to share actively. The cost of the system's construction in data management departments is gradually compensated by the incentives of higher authorities and the offsetting gains of data sharing authority, and they tend to manage and coordinate with increasing due diligence.



(**a**) Government functional department 1.

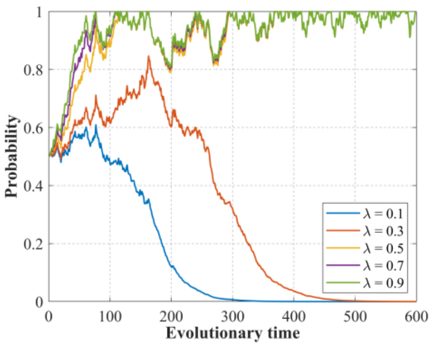


(**b**) Government functional department 2.

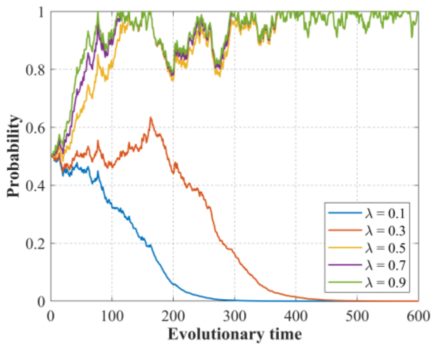


(**c**) Data management department.

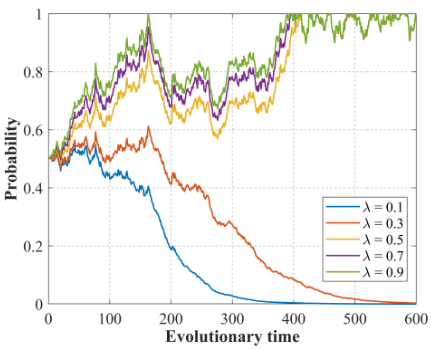
Figure 5. Influence of the interagency trust stock T of the government functional departments on the evolutionary paths of the tripartite subjects.



(**a**) Government functional department 1.



(**b**) Government functional department 2.



(**c**) Data management department.

Figure 6. Influence of the construction effort coefficient λ of the "good and bad reviews" system on the evolutionary paths of the tripartite subjects.

6. Discussion

In digital government practice, the flow of data breaks through departmental boundaries and shows significant cross-border characteristics. The traditional vertical structure and specialized division of labor in a section-based government tend to lead to fragmentation and a lack of holistic effectiveness of the governance process. How to promote cross-department data sharing has become a focus of public administration researchers. The Chinese government continues to explore data governance, with data management departments being formed around the country. There is no hierarchical relationship between the data management department and the government functional departments at the administrative level and, thus, there is no mandatory order in the process of cross-department data sharing among them. Therefore, a designed mechanism is needed to improve the participation strategies of the different actors to facilitate cross-sectoral data sharing efforts. In studies related to digital government and e-government, there are still a few studies that adopt EGT as a framework, focusing more on academic perspectives, such as organizational relationships and technology adoption, and less on the dynamic game relationship among different departments. In particular, the complexity and uncertainty of digital government construction as a complex system project has seriously affected the process of cross-department data sharing. Therefore, our study uses SEGM to investigate the evolution of strategies for participating in cross-department data sharing between data management departments and the different government functions, which has theoretical value for enhancing the degree of the digital transformation of government affairs and improving government public service capabilities. Compared with previous studies, the most important feature of our work is the use of mathematical modeling and simulation tools to analyze cross-department data sharing. Some studies have used the case study tool to analyze the "Visit Once" Administrative Service Reform in Zhejiang Province, China [12,13]. Their research was more focused on the summary and introduction of macro experience, and the analysis of the micro influence mechanism of some factors is insufficient. In addition, the model we used differs from the common models for information systems research, as summarized by Gacitua et al. [24]. We adopted evolutionary game theory, which is quite biological, as the explanatory framework for problem analysis. It can explain the interaction mechanism between different subjects more vividly to a certain extent. However, our analytical framework focuses on horizontal inter-agency data sharing. In this respect, the study by Ma et al. is more comprehensive, and they considered both horizontal and vertical dimensions [25].

In this study, based on an actual situation and a summary of the literature, six basic assumptions are proposed, according to which the payoff matrix of the different subjects is calculated. Individuals in EGT adjust their own strategies by imitating the strategies of other individuals, i.e., by replicating the dynamic update rule. We established the replication dynamic equations for each subject based on the payoff matrix, introduced white Gaussian noise to improve them and finally constructed a tripartite stochastic evolutionary game model for cross-department data sharing. Through mathematical derivation, we recognized that there exists an equilibrium solution to the model, and we further analyzed the conditions for the stability of the equilibrium solution using stochastic process theory. In the model, we deliberately focused on five key parameters and simulated them numerically, which are named the data sharing input intensity of government functional departments, the training intensity coefficient of digital thematic trainings organized by the data management department, the effect coefficient of the coordination mechanism for government data sharing, the interagency trust stock of the government functional departments and the construction effort coefficient of the "good and bad reviews" system. The impact of digital literacy and the stock of interagency trust relationships on the governance of government cross-department data sharing in previous studies is further corroborated in this paper [40,44]. In data sharing work practices, digital literacy can be divided into the literacy of cadres and the digital literacy of employees. In general, the improvement in the digital literacy of cadres has received more attention, because cadres are the initiators and leaders of building digital government, and their development is more critical than that of employees. Our study does not distinguish between these two classifications of practice, as we believe that interdepartmental collaboration requires training in digital literacy for any staff member. Moreover, we also considered two institutional designs with Chinese characteristics (the coordination mechanism of government data sharing and the "good and bad reviews" system). Figures 4 and 6 show the simulation of the effect of these two systems on cross-department data sharing, and it can be seen that they have a more significant impact on the strategic trajectory of the data management department. In concrete practice, the coordination mechanism for government data sharing is generally realized by the government in conjunction with multiple functional departments to form a deliberative coordination body, with the data management agency as the lead conferring department. In fact, our study supports the further extension of this characteristic institutional exploration; ultimately, the authority of the data management authorities does need to be further enhanced in real-life contexts. From the existing established data management departments, their influence on other functional departments is not significant, because they may all have the same rank. In addition, the data management department's finances are largely influenced by the local government, and the digital government construction requirements of the central government may not be well implemented. China has also announced the formation of a National Data Bureau in the two recently concluded sessions (NPC and CPPCC), which provides strong institutional support to further enhance cross-sector data sharing. This new change needs to be taken into consideration in further studies, as the establishment of the National Data Bureau will inevitably change the status and functions of the previous data management agencies. Another improvement for future research that can be expanded is the introduction of real cases to further refine the game relationship and make it more relevant to real situations.

7. Conclusions and Limitations

7.1. Conclusions

Based on EGT, this paper abstracts the real problem of cross-department data sharing in the construction of digital government into a game relationship of three subjects, and it constructs a stochastic evolutionary game model. We analyzed the strategy evolution and steady-state conditions of the data management department and different government functional departments involved in a cross-department data sharing process under the influence of different factors. The impact of several key factors on the cross-department data sharing game system was also analyzed through numerical simulation. The results of the study show that the cross-department data sharing process exists in a steady state, in which all three subjects choose an active strategy. The increased input intensity of data sharing by the government functional departments can further enhance the externality effect of data sharing and can motivate functional departments to choose to actively share, while also enhancing the willingness of the data management department to manage with due diligence. The accumulation of interagency trust relationship stock can gradually dissolve the perceived differences in data sharing among different departments. Improving the coordination mechanism of government data sharing can increase the accumulation of the interagency trust stock of government functional departments and make them actively participate in data sharing, as well as strengthen the coordination ability of the data management department among functional departments and motivate them to manage with due diligence. In addition, the construction of a "good and bad reviews" system can be a positive strategy for government functional departments and the data management agency to form external discipline and regulation and to promote their more active participation in cross-department data sharing.

7.2. Main Contributions

The main contribution of this paper is reflected in both theoretical and practical dimensions.

From the perspective of theoretical development, unlike most previous studies that focused on the factors that influence data sharing in the process of government digital transformation, this paper considers discussing inter-agency relationships as the entry point of the study. Second, this paper introduces the stochastic evolutionary game model into the study of digital government, which provides a new research framework and research path. The advantage of a stochastic evolutionary game over traditional evolutionary games is that it introduces a stochastic function to simulate the real environment with random disturbances. This makes our simulation results more consistent with realistic situations, because the idealized canonical model does not exist in reality. Finally, we used mathematical derivation to verify that there are steady-state strategy points in the cross-department data sharing process, and this result provides a basis for further improving cross-department data sharing through mechanism design.

From the perspective of practical significance and social impact, the practical significance of our work is mainly reflected in three aspects: departmental cooperation, institutional power and mechanism exploration. First, the interagency trust relationship stock supports the positive effect of prior cross-department cooperation on data sharing. Therefore, in concrete practice, government departments should strengthen inter-department consultation and collaboration on different public affairs in order to build up the stock of inter-institutional trust relationships. Second, the findings of this paper provide support for improving the political status of data management agencies. The elevated political status of the data management agency can enhance its influence on other functional departments, thus allowing cross-department digital government building conflicts to be untangled in administrative practice. Third, exploring and promoting distinctive mechanisms is also a practical initiative supported by the conclusions of this paper. In particular, the use of a mechanism to introduce the public as external supervision can play a good role in the function of supervision.

7.3. Implications

In order to promote the further development of data sharing in the construction of digital government, the following countermeasures are proposed in conjunction with the conclusions of this paper:

(1) Adjust and optimize the functional structure of data management departments and enhance the coordination ability of data management departments for cross-sector data sharing. What a digital government achieves is a holistic leap from the original government form to the digital space. This process requires disrupting and reshaping functional processes to adapt them to the needs of governance practices in the digital space. In the process, functional departments are caught in compartmentalization, and the data management department is required to play a coordinating role of service support, communication and coordination. The current digitalization of functional departments is only limited to some lightweight service areas, confined to the approval and processing of some single, simple matters and not deep into the core functions, partly because the coordination function of the data management department has not yet been effectively played, and because the data management department and functional departments have not yet formed comprehensive coordination and a fully integrated relationship. Therefore, it is necessary to further optimize and reform the responsibilities and authority of data management departments, to optimize their ranking position in the sequence of government departments and to enhance the coordinating function of the data management department in various forms, such as expanding and upgrading its authority.

(2) Improve and upgrade the system's construction related to data sharing, especially by exploring and promoting the coordination mechanism of government data sharing and a characteristic governance system, such as "good and bad reviews". Improve the incentive guidance mechanism for cross-department data sharing and stimulate functional departments to change from "reluctant to share" to "active to share" and "willing to share" through various forms of data sharing incentive benefits to further stimulate the endoge-

nous motivation of government departments and staff to work on innovation and service improvement. In addition, further enhance the supervision and incentives of public and external organizations, incorporate the "good and bad reviews" system into departmental performance evaluations, provide commendations and rewards to departments with good reviews in government sharing and seriously punish the departments with bad reviews to form an external disciplinary force for government data sharing. Moreover, actively build a data sharing security system, regularly conduct dynamic evaluations of the security of the data sharing environment and introduce new technologies and means to enhance the security of data sharing to reduce the perception of expected losses from data sharing by functional departments.

(3) Strengthen input support for data sharing, while enhancing synergy and cooperation among different functional departments. Relying on the existing digital government special action plan, increase and improve investment in digital government infrastructure around key areas. It is necessary to gradually integrate and improve the direct digital connection and sharing channels among functional departments with the help of the existing integrated digital middle platform and to open up cross-department data sharing channels. Increase investment in digital government innovation and explore the innovative application of blockchain, artificial intelligence and other technologies in government data sharing. Moreover, strengthen interfunctional synergy and cooperation. Enhance the accumulation of interagency trust stock through the cross-collaboration of traditional services, and reduce barriers to collaboration among functional departments in cross-department data sharing.

7.4. Limitations and Future Research

Similar to the transformation of enterprise information technology, the construction of digital government has a life cycle. The characteristics of cross-department data sharing do not behave exactly the same at different stages. Thus, the game should not only be dynamic but can also be a multistage model, where the set of strategies at each stage may not be consistent. In addition, due to the fact that the differences among functional departments are also very obvious, a real policy environment can be better simulated if the agent-based model (ABM) approach is used. Therefore, we suggest that future research be conducted according to three aspects. First, scholars can construct a multi-stage game model based on the life cycle of digital transformation, which helps to refine the game process more. Second, the risk preference characteristics of different subjects should be considered, for example, by introducing prospect theory to explain the influence of subjects' risk preference characteristics on behavioral decisions. Third, ABM rather than differential equations can be considered to better model the policy environment of digital government construction. In addition, system dynamics is a feasible modeling idea to consider the interactions of complex factors.

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References

1. Li, G.; Hou, Y.; Wu, A. Fourth Industrial Revolution: Technological Drivers, Impacts and Coping Methods. *Chin. Geogr. Sci.* **2017**, *27*, 626–637. [CrossRef]
2. Ingrams, A. Public Values in the Age of Big Data: A Public Information Perspective. *Policy Internet* **2019**, *11*, 128–148. [CrossRef]
3. Dunleavy, P.; Margetts, H.; Bastow, S.; Tinkler, J. New public management is dead—Long live digital-era governance. *J. Publ. Adm. Res. Theor.* **2006**, *16*, 467–494. [CrossRef]
4. Margetts, H.; Dunleavy, P. The second wave of digital-era governance: A quasi-paradigm for government on the Web. *Philos. T R. Soc. A* **2013**, *371*, 1987. [CrossRef]
5. Huang, H.; Sun, X. The Agency of Data Governance of Local Government in China: Status Quo and Pattern. Chin. *Public Adm.* **2018**, *402*, 31–36. (In Chinese)
6. Mao, Z.; Wu, J.; Liu, M. A CIO-centric local government data-sharing leadership ecosystem in China. *Inform. Dev.* **2021**. [CrossRef]
7. Gao, X. State-Society Relations in China's State-Led Digitalization: Progress and Prospects. *China Rev.* **2020**, *20*, 1–11. Available online: https://www.jstor.org/stable/26928109 (accessed on 13 April 2023).
8. Susha, I.; Rukanova, B.; Zuiderwijk, A.; Gil-Garcia, J.R.; Hernandez, M.G. Achieving voluntary data sharing in cross sector partnerships: Three partnership models. *Inform Organ* **2023**, *33*, 100448. [CrossRef]
9. Hasanah, S.; Pratama, I.N.; Rahmat, A.F.; Kurniawan, C. Digital Government in Social Sciences Discipline: Mapping Pivotal Features and Proposed Theoretical Model. *J. Ilm. Peuradeun.* **2023**, *11*, 195–220. [CrossRef]
10. Ramon Gil-Garcia, J.; Sayogo, D.S. Government inter-organizational information sharing initiatives: Understanding the main determinants of success. *Gov. Inform. Q.* **2016**, *33*, 572–582. [CrossRef]
11. Myeong, S.; Kwon, Y.; Seo, H. Sustainable E-Governance: The Relationship among Trust, Digital Divide, and E-Government. *Sustainability* **2014**, *6*, 6049–6069. [CrossRef]
12. Huang, B.; Yu, J. Leading Digital Technologies for Coproduction: The Case of "Visit Once" Administrative Service Reform in Zhejiang Province, China. *J. Chin. Polit. Sci.* **2019**, *24*, 513–532. [CrossRef]
13. Gao, X.; Tan, J. From Web to Weber: Understanding the Case of "One-Go at Most" as ICT-Driven Government Reform in Contemporary China. *China Rev.* **2020**, *20*, 71–97.
14. Lindgren, I.; Madsen, C.O.; Hofmann, S.; Melin, U. Close encounters of the digital kind: A research agenda for the digitalization of public services. *Gov. Inform. Q.* **2019**, *36*, 427–436. [CrossRef]
15. Bouguettaya, A.; Yu, Q.; Liu, X.; Malik, Z. Service-Centric Framework for a Digital Government Application. *IEEE T Serv. Comput.* **2011**, *4*, 3–16. [CrossRef]
16. Dawes, S.S.; Cresswell, A.M.; Pardo, T.A. From "Need to Know" to "Need to Share": Tangled Problems, Information Boundaries, and the Building of Public Sector Knowledge Networks. *Public. Admin Rev.* **2009**, *69*, 392–402. [CrossRef]
17. Asgarkhani, M. Digital government and its effectiveness in public management reform—A local government perspective. *Public. Manag. Rev.* **2005**, *7*, 465–487. [CrossRef]
18. Pardo, T.A.; Nam, T.; Burke, G.B. E-Government Interoperability: Interaction of Policy, Management, and Technology Dimensions. *Soc. Sci. Comput. Rev.* **2012**, *30*, 7–23. [CrossRef]
19. Almeida, V.; Filgueiras, F.; Gaetani, F. Digital Governance and the Tragedy of the Commons. *IEEE Internet Comput.* **2020**, *24*, 41–46. [CrossRef]
20. Susha, I.; Pardo, T.A.; Janssen, M.; Adler, N.; Verhulst, S.G.; Harbour, T. A Research Roadmap to Advance Data Collaboratives Practice as a Novel Research Direction. *Int. J. Electron. Gov. Res.* **2018**, *14*, 11. [CrossRef]
21. Drake, D.B.; Steckler, N.A.; Koch, M.J. Information sharing in and across government agencies—The role and influence of scientist, politician, and bureaucrat subcultures. *Soc. Sci. Comput. Rev.* **2004**, *22*, 67–84. [CrossRef]
22. Fedorowicz, J.; Gogan, J.L.; Culnan, M.J. Barriers to Interorganizational Information Sharing in e-Government: A Stakeholder Analysis. *Inform. Soc.* **2010**, *26*, 315–329. [CrossRef]
23. Moon, M.J.; Lee, J.; Roh, C. The Evolution of Internal IT Applications and e-Government Studies in Public Administration: Research Themes and Methods. *Admin Soc.* **2014**, *46*, 3–36. [CrossRef]
24. Gacitua, R.; Astudillo, H.; Hitpass, B.; Osorio-Sanabria, M.; Taramasco, C. Recent Models for Collaborative E-Government Processes: A Survey. *IEEE Access* **2021**, *9*, 19602–19618. [CrossRef]
25. Ma, D.; Zhou, J.; Zuo, M. Inter-agency information sharing for Chinese e-government development: A comparison between vertical and horizontal dimensions. *Inform. Technol. Dev.* **2022**, *28*, 297–318. [CrossRef]
26. Yang, T.; Maxwell, T.A. Information-sharing in public organizations: A literature review of interpersonal, intra-organizational and inter-organizational success factors. *Gov. Inform. Q.* **2011**, *28*, 164–175. [CrossRef]
27. Wu, Y.; Bauer, J.M. E-government in China: Deployment and driving forces of provincial government portals. *Chin. J. Commun.* **2010**, *3*, 290–310. [CrossRef]
28. Zhou, L.; Chen, L.; Han, Y. "Data stickiness" in interagency government data sharing: A case study. *J. Doc.* **2021**, *77*, 1286–1303. [CrossRef]
29. Lo, O.; Buchanan, W.J.; Sayeed, S.; Papadopoulos, P.; Pitropakis, N.; Chrysoulas, C. GLASS: A Citizen-Centric Distributed Data-Sharing Model within an e-Governance Architecture. *Sensors* **2022**, *22*, 2291. [CrossRef]
30. Gans, R.B.; Ubacht, J.; Janssen, M. Governance and societal impact of blockchain-based self-sovereign identities. *Policy Soc.* **2022**, *41*, 402–413. [CrossRef]

31. Alexopoulos, C.; Charalabidis, Y.; Loutsaris, M.A.; Lachana, Z. How Blockchain Technology Changes Government: A Systematic Analysis of Applications. *Int. J. Public. Adm. Dig. Age* **2021**, *8*, 20. [CrossRef]
32. Yu, Z.; Rehman Khan, S.A. Evolutionary game analysis of green agricultural product supply chain financing system: COVID-19 pandemic. *Int. J. Logist-Res. Appl.* **2022**, *25*, 1115–1135. [CrossRef]
33. Zhang, M.; Li, H.; Song, Y.; Li, C. Study on the heterogeneous government synergistic governance game of haze in China. *J. Environ. Manag.* **2019**, *248*, 109318. [CrossRef]
34. Rong, J.; Zhu, L. Cleaner Production Quality Regulation Strategy of Pharmaceutical with Collusive Behavior and Patient Feedback. *Complexity* **2020**, *2020*, 1920523. [CrossRef]
35. Liu, J.; Song, Y.; An, S.; Dong, C. How to Improve the Cooperation Mechanism of Emergency Rescue and Optimize the Cooperation Strategy in China: A Tripartite Evolutionary Game Model. *Int. J. Environ. Res. Pub. Health* **2022**, *19*, 1326. [CrossRef]
36. Shan, S.; Zhang, Z.; Ji, W.; Wang, H. Analysis of collaborative urban public crisis governance in complex system: A multi-agent stochastic evolutionary game approach. *Sustain. Cities Soc.* **2023**, *91*, 104418. [CrossRef]
37. Li, J.; Wang, J.; Lee, H.; Zhao, X. Cross-regional collaborative governance in the process of pollution industry transfer: The case of enclave parks in China. *J. Environ. Manag.* **2023**, *330*, 117113. [CrossRef]
38. Xu, X.; Yang, Y. Analysis of the Dilemma of Promoting Circular Logistics Packaging in China: A Stochastic Evolutionary Game-Based Approach. *Int. J. Environ. Res. Pub. Health* **2022**, *19*, 7363. [CrossRef]
39. Fan, J.; Zhang, P.; Yen, D.C. G2G information sharing among government agencies. *Inform. Manag.* **2014**, *51*, 120–128. [CrossRef]
40. Chohan, S.R.; Hu, G. Strengthening digital inclusion through e-government: Cohesive ICT training programs to intensify digital competency. *Inform. Technol. Dev.* **2022**, *28*, 16–38. [CrossRef]
41. Welch, E.W.; Feeney, M.K.; Park, C.H. Determinants of data sharing in US city governments. *Gov. Inform. Q.* **2016**, *33*, 393–403. [CrossRef]
42. Harvey, F.; Tulloch, D. Local-government data sharing: Evaluating the foundations of spatial data infrastructures. *Int. J. Geogr. Inf. Sci.* **2006**, *20*, 743–768. [CrossRef]
43. Gil-Garcia, J.R.; Pardo, T.A. E-government success factors: Mapping practical tools to theoretical foundations. *Gov. Inform. Q.* **2005**, *22*, 187–216. [CrossRef]
44. Gil-Garcia, J.R.; Chengalur-Smith, I.; Duchessi, P. Collaborative e-Government: Impediments and benefits of information-sharing projects in the public sector. *Eur. J. Inform. Syst.* **2007**, *16*, 121–133. [CrossRef]
45. Scholl, H.J.; Kubicek, H.; Cimander, R.; Klischewski, R. Process integration, information sharing, and system interoperation in government: A comparative case analysis. *Gov. Inform. Q.* **2012**, *29*, 313–323. [CrossRef]
46. Onyango, G. Organizational Trust and Accountability Reforms in Public Management: Analysis of Inter-agency Implementation Relations in Kenya. *Int. J. Public. Adm.* **2019**, *42*, 1159–1174. [CrossRef]