

Article

A New Strategy to Solve “the Tragedy of the Commons” in Sustainable Grassland Ecological Compensation: Experience from Inner Mongolia, China

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Abstract: Based on the principle of “who protects and benefits will compensate”, in recent years, many Chinese herders have begun to voluntarily participate in sustainable grassland ecological compensation by donating money. However, this traditional strategy may have brought about “the tragedy of the commons”. A new strategy described as “wealthy herders pay money, ordinary herders participate in supervision, and relevant departments post a list of participants at the end of each month”, which was trialed in the Keshiketeng Banner, Inner Mongolia, China, attempts to solve “the tragedy of the commons”. This new strategy is neither “Leviathan” nor “Privatization”; it creates a third way for grassland herders to achieve spontaneous cooperation in protecting grassland ecology. This article presents a theoretical analysis framework and experimental simulation method using this new strategy. Considering the importance of face culture and gossip in herders’ social lives, this study used a public goods game (PGG) model to analyze and experimentally simulate the effect of this new strategy. The simulated data show the following: (1) Compared with the traditional strategy, this new strategy promotes cooperation more effectively. It requires less money, time and human capital from herders and can mobilize more herders to participate in sustainable grassland ecological compensation, leading to the emergence of a cooperation equilibrium among herders. (2) In this new strategy, the total contributions of herders are inversely proportional to herders’ “reputation tolerance”, and they are directly proportional to herders’ “income level”, “total budget” and “satisfaction and emotion”. The cooperation level is inversely proportional to “reputation tolerance” and “income level” and directly proportional to “total budget” and “satisfaction and emotion”. (3) The advantage of this new strategy is that it is robust to changes in the exogenous coefficient. Our research contributes to the application of the PGG model in the sustainable development of various resources and developing new approaches to mitigating “the tragedy of the commons”.

Keywords: the tragedy of the commons; sustainable grassland ecological compensation; public goods game model



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1. Introduction

Grassland is the most widely distributed vegetation type on earth, with a total area of 5.25 billion hectares, accounting for 40.5% of the global land area, which is the second largest terrestrial ecosystem after forest ecosystems. The global distribution of grasslands is uneven, with large proportions in Africa, Asia, Latin America and Oceania, and the smallest in Europe. The top 10 countries in terms of grassland area are Australia, Russia, China, the United States, Canada, Kazakhstan, Brazil, Argentina, Mongolia and Angola. Sustainable Grassland Ecological Compensation (SGEC) is an important institutional arrangement for the construction of grassland ecological communities; its purpose is to encourage the protection and construction of grassland ecology [1–3]. In the world as a whole, SGEC mainly relies on policy promotion, for example, in the United States, three major policies of ecological compensation for grassland, including the Conservation Reserve Program

(CRP), Grazing Lands Conservation Initiative (GLCI) and Environmental Quality Incentive Program (EQIP), were implemented in 1985, 1991 and 1996, respectively, and are still in effect today. Since 1935, Canada has implemented the Prairie Farm Revival Act, which has not only enhanced the ecological value of degraded grasslands, but also improved land productivity. In addition, government financial support and public participation are also common forms of SGEC and have been widely applied in China.

In China, the traditional strategy used to guide herders to voluntarily participate in SGEC was to encourage them to contribute to a grassland ecological construction fund, which was used to compensate for the ecological elements of the grassland. However, this approach led to a low level of cooperation: some wealthy and environmentally conscious herders actively donated money to compensate for the grassland ecology, but due to bounded rationality, other herders behaved selfishly and even increased the number of livestock grazing without permission, which resulted in an increase in livestock grazing and further depletion of the grassland ecology. For example, since SGEC was implemented in 2018, the number of grazing livestock on the grasslands of Inner Mongolia's XilinGol League in China has not decreased; in fact, it had increased by 2.45% by the end of 2021. Such a social dilemma resulting from the conflict between personal and collective interests is known as "the tragedy of the commons", which has been plaguing the management of public pools of resources for years [4–6]. There are two traditional ways to solve "the tragedy of the commons" in public resource management: "Leviathan", which means that resources are collected, distributed and managed through the state machine [7–9]; and "Privatization", which clearly defines the property rights of each resource [10–12]. In the Keshiketeng Banner, Inner Mongolia, China, a third way of solving "the tragedy of the commons", based on the living customs of herders, has been explored. This new strategy is neither Leviathan nor Privatization but a kind of self-management of public resources. It is necessary to analyze this new strategy and verify its effectiveness through a theoretical model in order to promote its use and broaden ways of mitigating "the tragedy of the commons".

China is the third largest country in terms of grassland area globally, after Australia and Russia. Grassland accounts for 41.7% of China's total land area, and it is the largest terrestrial ecosystem in China. However, in the past 40 years, grassland degradation, desertification and salinization have become serious problems affecting the sustainable development of grassland [13,14]. In 2011, the Chinese government implemented large-scale grassland ecology compensation practices covering 13 major grassland pastoral provinces (districts), including Inner Mongolia, Xinjiang, Tibet, Yunnan and Sichuan. In May 2017, the Ministry of Finance and the Ministry of Agriculture of China jointly issued the Administrative Measures for Agricultural Production Development Funds, which encourages herders to voluntarily participate in grassland ecological compensation. In Xinjiang, Sichuan, Yunnan and other provinces, based on the principle of "who protects and benefits will compensate", wealthy herders are encouraged to participate in grassland ecology compensation through donations and other monetary means to protect grassland ecology and ease the government's financial burden. However, the practical application of these measures has shown that this leads to "the tragedy of the commons" in SGEC. Researchers recommended that the property rights of grassland areas through Leviathan or Privatization methods [15,16] should be defined based on the Coase theorem, which holds that as long as the property rights are clear and the transaction cost is zero or low enough, no matter whom the property rights are assigned to initially, the allocation of resources will achieve Pareto Optimality [17]. Therefore, in countries such as Australia, the United States and Germany, fences are used to clarify the property rights of grassland [18,19], and livestock are kept within fences for stocking. Australia has strictly defined grazing areas, clarified property rights of grassland, implemented grazing breaks or reduced stocking rates in different grazing areas, and ranchers are encouraged to implement sustainable grazing strategies through financial subsidies. For instance, the government subsidizes 50 per cent of the cost of transporting livestock between different grazing areas [20,21].

In order to protect grassland ecology, ranchers in the southwest of the United States proposed a “grassland bank”. By clarifying grassland property rights, they delimit non-grazing grassland and promote the sustainable development of grassland resources [22]. By defining the property rights of grassland as public pasture, private pasture and collective pasture, Germany is able to implement different ecological protection policies for different pasture [23,24]. Based on the experience of grassland management in developed countries, a grassland contractual management responsibility system has been implemented in China to clarify the grassland property rights [25,26]. However, Zellweger et al. [27] argued that this approach had little effect in alleviating the deterioration of grassland ecological environments in China. Some scholars attribute this outcome to differences in Chinese and foreign cultures [28,29]. Chinese herders are different to Western pastoral herders; they are accustomed to a gregarious life and grazing [30,31] and jointly resist natural disasters in grassland. The implementation of the fenced livestock system with clear property rights caused the relationships between herders to become less relaxed and amiable [32–34] and impaired their abilities to resist grassland degradation in groups [35–37]. In order to restore herders’ abilities to act in groups, the Chinese government has recently encouraged herders to voluntarily participate in SGEC.

In contrast to the emphasis on policy promotion or grassland property rights in SGEC in other countries, the new strategy explored in the Keshiketeng Banner, Inner Mongolia, China, is a typical case of mobilizing herders to voluntarily participate in SGEC without clarifying the property rights of grassland. This new strategy is described as “wealthy herders pay money, ordinary herders participate in supervision, and relevant departments post a list of participants at the end of each month”. According to this strategy, wealthy herders donate money to support the restoration and construction of grassland ecology while less wealthy herders invest manpower and time to participate in grassland ecology supervision, and once overgrazing occurs, they immediately stop it or report it to the government; then, at the end of each month, relevant departments (local governments or herders associations) post a list of herders who paid money and/or participated in supervision on the local government website or other prominent sites in the pastoral areas. This new strategy reduced the amount of local livestock grazing in the Keshiketeng Banner by 3.14% from 2018 to 2021, and the grassland pasture ecology has now been effectively restored. These findings caused us to deeply reflect on the following questions: How does this new strategy promote the emergence of herders’ spontaneous cooperation with SGEC? Is it impossible for this new strategy to promote and implement sustainable grassland management globally due to differences in cultures? How does this new strategy mitigate “the tragedy of the commons”, and how can we construct a theoretical framework to simulate this strategy? The public goods game (PGG) model has been widely used to simulate “the tragedy of the commons” in common pool resource management. Related research into the PGG model was jointly initiated by Nowak and May [38] to describe and simulate “the tragedy of the commons”. In a PGG model, there is a well-mixed population of N participants. n_c ($n_c \leq N$) cooperative participants input resources into the public pool, and the cooperative effect of all inputs is amplified by a synergy factor [39,40]; then, the resources in the public pool are evenly distributed to all participants. Obviously, for a rational participant, the optimal strategic choice for him/her is to become a defective participant and freeloader from the common resources.

Many researchers have explored innovative mechanisms to improve the PGG model from different perspectives, including the punishment mechanism [41–45], reputation maintenance mechanism [46–50], reward mechanism [51–53], group diversity mechanism [54–56], tolerance mechanism [57–59] and emotional mechanism [60–64]. To date, the PGG model has been widely adopted in the management of public cultural resources [65], public roads [66] and public medical resources [67]. The participants in a PGG model are gathered in a spatial social structure; all participants live in social groups and have social relationships with neighbors, relatives and friends. Therefore, participants’ decision making is affected by their surrounding social relationships. The spatial social structure of partici-

pants in a PGG model is similar to the structure of society in grasslands, and the problem described in a PGG model is similar to “the tragedy of the commons” in SGEC. Therefore, the PGG model can be used to resolve “the tragedy of the commons” in SGEC. Accordingly, this article uses PGG model as the basic model to construct a theoretical analysis framework of the new strategy explored in the Keshiketeng Banner, Inner Mongolia.

The rest of this article is organized as follows: Section 2 presents a theoretical analysis framework for the new strategy, including the theoretical basis of the new strategy, the framework of an improved PGG model for the new strategy and the variables employed in the improved PGG model. Section 3 describes the experimental data simulation and analysis results of the new strategy. Section 4 discusses the policy implications, model comparison and PGG model innovation. Section 5 presents the conclusions.

2. Materials and Methods

This article intends to construct a theoretical analysis framework for the new strategy based on the PGG model.

2.1. The Theoretical Basis of the New Strategy

In order to examine the new strategy, we first need to analyze its theoretical basis. The ecological compensation strategy used in the Keshiketeng Banner, Inner Mongolia, is consistent with “the third way” proposed by Nobel economist Elinor Ostrom on resolving “the tragedy of the commons” [68,69]: a group of interdependent people design basic rules according to their social behaviors and overcome problems in managing their public resources, achieving sustainable common interests through independent efforts (not completely directed by the government). In her masterpiece, *Governing the Commons* [68], Elinor Ostrom proved the existence of this third method by discussing the tragedy of grasslands, forests, lakes and other public resource commons. The new strategy to mitigate “the tragedy of the commons” explored in Keshiketeng Banner, Inner Mongolia, is an embodiment of “the third way” described by Elinor Ostrom. It makes full use of herders’ habits of attaching great importance to face culture, relying on the speed of gossip to control freeloading herders and promoting the emergence of spontaneous cooperation in SGEC; this specific process is divided into the two aspects described below.

On the one hand, this new strategy considers the different incomes of herders in SGEC. Indeed, in Inner Mongolia’s Keshiketeng Banner, herders’ income levels differ, and it is impossible for most herders to voluntarily donate money to support grassland ecological compensation. Some herders have difficulty participating in grassland ecological construction by donating money because of their low income [70–72]. If the SGEC mechanism only allows herders to donate money, then all herders with low incomes will be excluded from the SGEC. In fact, the sustainable development of grassland ecology not only requires monetary compensation for the construction of grassland ecological elements but also herders’ human resources for the supervision of defective behaviors.

On the other hand, in this new strategy, cooperation emerges through the constraints imposed by gossip among herders. Traditionally, Chinese grassland herders are accustomed to a gregarious life and attach great importance to face culture [73–75]. In their social life, most herders choose to obey social rules and be cooperators, while some herders choose to break social rules and become defectors. Once herders’ defective behaviors break the social bottom line, they become the subject of gossip among neighbors, which damages their reputation. In order to improve their reputation, herders have to adjust their behaviors in order to gain social recognition (this process is described in Figure 1).

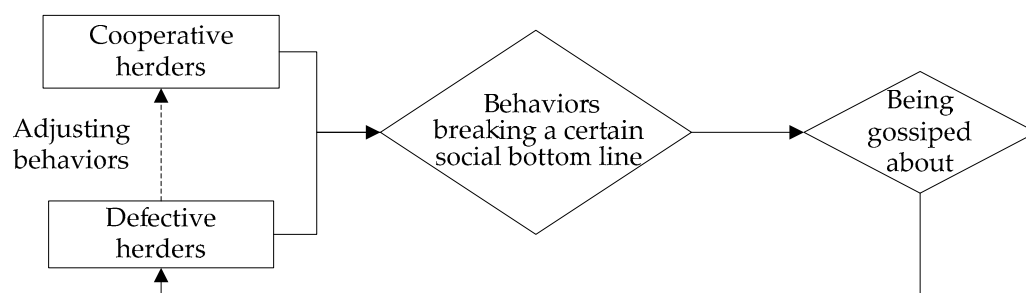


Figure 1. The process of behavior adjustment of herders under the influence of face culture.

Therefore, this article constructs an improved PGG model as our theoretical analysis framework for this new strategy, after investigating the herders in the Keshiketeng Banner, Inner Mongolia.

2.2. An Improved PGG Model for the New Strategy

This article labels the new strategy explored in the Keshiketeng Banner, Inner Mongolia, China, the MSS (Money–Supervision Strategy): wealthy herders choose to donate money, while less wealthy herders participate in the supervision of the SGEC to prevent overgrazing. Meanwhile, in order to compare the effectiveness of this new strategy, this article compares the MSS with the traditional strategy: wealthy herders voluntarily donate money to facilitate grassland ecological reconstruction, which we define as the MOS (Money-Only Strategy).

There are two kinds of participants in these two strategies (the MSS and MOS): co-operators (C), and defectors (D). Cooperators (C) are herders who choose to pay money or participate in supervision, and other herders who do nothing or even increase their livestock privately are called defectors (D). We use the PGG model to theorize the MSS, and the newly built theoretical analysis framework is shown in Figure 2. Compared with the traditional PGG model, the process of achieving a cooperation equilibrium in the MSS is more complicated.

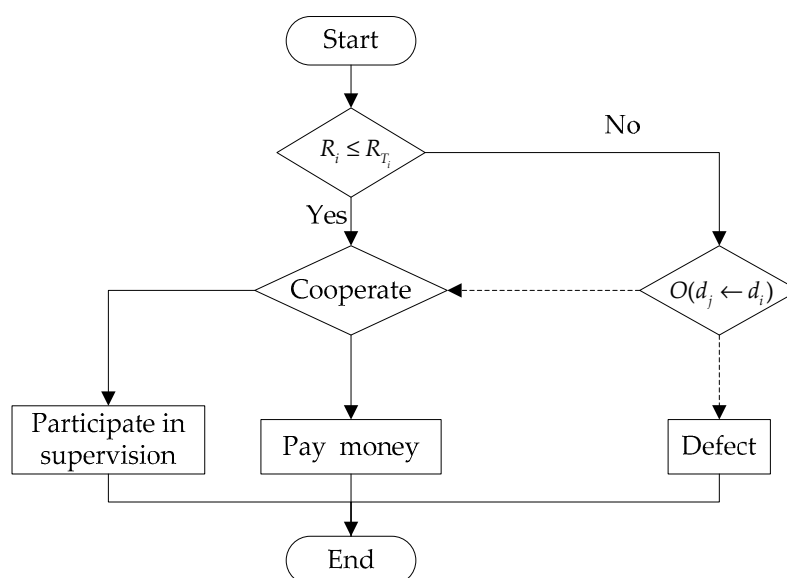


Figure 2. The theoretical analysis framework of MSS.

Here, let us introduce Figure 2 briefly.

First, as described above, herders have bottom lines of reputation [72], which we call reputation tolerance R_T . If herder i 's reputation $R_i \leq R_T$, then the herder will choose

to cooperate—donate money with a probability η_i or participate in supervision with a probability $(1 - \eta_i)$ —to improve his/her reputation, which is described as follows:

$$\eta_i = \begin{cases} \varphi_i, & 0 \leq \varphi_i \leq 1 \\ 1, & \varphi_i > 1 \end{cases} \quad (1)$$

where φ_i is herder i 's income level, which obeys a normal distribution, i.e., $\varphi_i \sim N(\bar{\varphi}_i, (\frac{\bar{\varphi}_i}{5})^2)$. $\bar{\varphi}_i$ denotes the average income level of herders in a certain area.

Secondly, when $R_i > R_T$, face culture is no longer an issue that herders need to consider; herders do not need to maintain their own reputation, while herders' decision making is usually influenced by the behavior of neighbors. Then, herders imitate and follow the decisions of their neighbors or relatives, which we use $O(d_j \leftarrow d_i)$ to describe, where d_i and d_j represent the decision made by herder i and his/her neighbor herder j , respectively. In this case, the herder faces different decision-making situations under MOS and MSS. Therefore, we separately present the decision-making process of herders under the MOS and MSS in (I) and (II) below.

(I) In the MOS, if $R_i > R_T$, whether herder i chooses to be a cooperator (C) or a defector (D) depends on the possibility of $O(d_j \leftarrow d_i)$:

$$O(d_j \leftarrow d_i) = \begin{cases} \frac{1}{1+\exp[(P_i-P_j)/\tau]} + s\chi - \gamma, & c_j > 0 \\ \frac{1}{1+\exp[(P_i-P_j)/\tau]} - s\chi + \gamma, & c_j = 0 \end{cases} \quad (2)$$

where $s\chi$ denotes the effect of satisfaction on herder i 's decision making; γ represents the negative effect of the MOS because it prevents poor herders from being cooperators. γ obeys the independent random distribution ($0.5 \leq \gamma < 1$). When $c_j > 0$, which means herder i 's neighbor, herder j , is a cooperator, to a large extent, herders follow their neighbors' strategy to be a cooperator. When $c_j = 0$, neighbor j is a defector.

(II) In the MSS, both donating money and participating in supervision are used by herders to cooperate. If $R_i > R_T$, whether herder i chooses to be a cooperator (C) or a defector (D) depends on the possibility of $O(d_j \leftarrow d_i)$:

$$O(d_j \leftarrow d_i) = \begin{cases} \frac{1}{1+\exp[(P_i-P_j)/\tau]} + s\chi + e\omega, & c_j > 0 \\ \frac{1}{1+\exp[(P_i-P_j)/\tau]} - s\chi - e\omega, & c_j = 0 \end{cases} \quad (3)$$

where $e\omega$ denotes the effect of emotion on herder i 's decision making. When $c_j > 0$, herder i 's neighbor j is a cooperator, the herder is affected by satisfaction, $s\chi$, and emotion, $e\omega$, and chooses to follow his/her neighbor's strategies. When $c_j = 0$, neighbor j is a defector, and the influence of the neighbor causes satisfaction, $s\chi$, and emotion, $e\omega$, to have a negative impact on the herder's choice to cooperate.

If $R_i \leq R_T$, herder i never considers his/her reputation, i.e., herder i will try to maximize his/her payoff by imitating one of his/her neighbors with a probability as follows:

$$O(d_j \leftarrow d_i) = \frac{1}{1 + \exp[(P_i - P_j)/\tau]}, \quad (4)$$

where τ denotes the amplitude of environment noise. We set $\tau = 0.1$ based on previous studies [38–40].

From the process of (I) and (II), we can conclude that the decision-making process of herders depends on the following parameters: R_T , P_i and $s \cdot e$. The next part of this section introduces these parameters.

2.2.1. Reputation Tolerance, R_T

The game of SGEC among herders is staged on a social network, assuming each herder has a different number of neighbors (n_{ei}) belonging to $n_{ei} + 1$ PGG groups. Gossip is one

of the important aspects of herders' conversations and communication [76,77]. Moreover, related research shows that gossip is helpful in promoting the emergence of cooperation among groups [78,79]. Therefore, when herders' names are posted at the end of each month on a donation list, the traditional face culture makes herders take different attitudes towards different herders: herders who are listed become the objects of appreciation, while herders who are always a defector in SGEC become the objects of gossipmongers and become disliked. In the process of spreading gossip, some neighbors will tell herder i that he/she has been gossiped about. Feedback from a neighbor would make herder i feel that his/her reputation has been enlarged or reduced by ΔR_i among the group. Therefore, at time step t , a herder's reputation, $R_i(t)$, can be described as follows:

$$R_i(t) = R_i(t-1) \pm \Delta R_i \quad (5)$$

Initially, every herder's reputation has an initial value $R_i(0)$ ($0 \leq R_i(0) \leq n_{ei}$), which obeys a normal distribution mean $n_{ei}/4$ and standard deviation $n_{ei}/9$, i.e., $R_i(0) \sim N(n_{ei}/4, (n_{ei}/9)^2)$. Considering the cognitive biases of different herders on reputation, ΔR_i is different for each herder. Therefore, we assume that it is a random value between 0 and $n_{ei}/100$, i.e., $\Delta R_i \in [0, n_{ei}/100]$. As mentioned above, in order to protect their reputation, herder i will cooperate in the next generation when $R_i \leq R_T$; otherwise, herder i 's decision will be made on the basis of a comprehensive consideration of payoff, P_i , and satisfaction and emotion, $s \cdot e$. We describe these factors below.

2.2.2. Payoff, P_i

As rational people, herders also value the personal payoff they receive from SGEC. According to previous studies [38–40], herders' initial contributions may obey the normal distribution with one mean. After the contributions of all herders are multiplied by the synergy factor, r , herders' total contribution value, P , is finally formed as $P = \sum r p_i^j p_j^i$ ($i, j \in \Omega_i$). Then, P is evenly divided among all herders. Correspondingly, the payoff, P_i , obtained by herder i can be calculated using the following expression:

$$P_i = \frac{P}{\Omega_i} = \sum_{j \in \Omega_i} P_i^j = \sum_{j \in \Omega_i} (r \frac{c_i^m + c_j^s}{n_{ei} + 1} - c_i) \quad (6)$$

where Ω_i denotes the set of PGG groups to which herder i belongs. j is one of the set of Ω_i , and c_i represents herder i 's contribution. Correspondingly, c_j is the contribution of herder j . r denotes the synergy factor. c_i^m and c_i^s represent the value of herders' contributions of donating money and participating in supervision, respectively. If herder i pays money, then $c_i = 1$. If herder i contributes nothing and becomes a defector, then $c_i = 0$. If herder i participates in supervision, then his/her contribution, c_i , can be calculated using the following formula:

$$c_i = \begin{cases} 1, & n_s < v_s \\ \frac{v_s}{n_s}, & n_s \geq v_s \end{cases} \quad (7)$$

where n_s represents the number of herders participating in supervision. v_s ($v_s = v \times f_{non}$) denotes the maximum amount of non-monetary contribution required for SGEC. V represents the total budget required for SGEC, and f_{non} ($0 < f_{non} < 1$) is the ratio of non-monetary contribution to the total budget for SGEC.

2.2.3. Satisfaction and Emotion, $s \cdot e$

Existing research shows that satisfaction is conducive to promoting the emergence of cooperation [80–82]. We use χ to describe the weight of satisfaction in herders' decision making. The satisfaction that participating in SGEC brings to herders, which is represented

by s , can be described by the ratio of herders' contributions accounting for the total SGEC budget V ; this can be expressed as follows:

$$s = \left(\frac{C_m + C_s}{V} \right)^2 - 1 \quad (8)$$

where C_m denotes the sum of monetary contributions donated by all herders in a certain area of the grassland, while C_s denotes the sum of non-monetary contributions (participation in supervision) provided by all herders.

Herders have particular feelings about the grasslands where their ancestors lived. Relevant studies show that emotions have a positive effect on the emergence of cooperation [83–86]. This is why the participation of herders in supervision is conducive to the formation of the sustainable development of grassland ecology. Herders' participation in the supervision of SGEC can cultivate their sense of cherishing grassland ecology. We use ω to donate the weight of emotional effect in herders' decision making, and we use e to describe the emotion effect, which is decided by consecutive generations of herders participating in supervision:

$$e = 1 - \exp(1 - \mu) \quad (9)$$

where μ denotes the consecutive generations participating in supervision. It can be seen from Equation (9) that if herders ceased to participate in supervision in SGEC, their emotion for the grassland would decline sharply. Table 1 provides a summary of all the variables used in this model.

Table 1. Model variables.

Variable	Definition and Description
R_i	Herder i 's reputation
R_T	Herder i 's reputation tolerance
ΔR_i	Changes in herder i 's reputation
η_i	The probability of a herder paying money
φ_i	Herder i 's income level
P_i	Herder i 's payoff level
N	The number of herders
n_{ei}	Number of neighbors of herder i
c_i	Herder i 's contributions
c_i^m	Herder i 's monetary contributions
c_i^s	Herder i 's contributions by participating in supervision
Ω	The set of PGG groups to which herder i belongs
r	The synergy factor
d_i	The strategy chosen by herder i
τ	The amplitude of environment noise
s	The effect of herder i 's satisfaction
χ	The weight of satisfaction in herder i 's decision making
γ	The negative effect of the MOS
e	The effect of herder i 's emotion
μ	The consecutive generations of herders participating in supervision
ω	The weight of emotion in herder i 's decision making
n_s	The number of herders participating in supervision in SGEC
V	The total budget required for SGEC
v_s	The maximum amount of non-monetary contributions required for SGEC
f_{non}	The ratio of non-monetary contributions to the total budget
C_m	The sum of monetary contributions donated by all herders in SGEC
C_s	The sum of non-monetary contributions provided by all herders in SGEC

3. Numerical Simulation Analysis and Results

In order to highlight the advantages of the MSS, this article compares the MSS and MOS through a large number of experimental numerical simulations; the purpose is to analyze:

- (I) The cooperation levels of the MSS and MOS and the speed with which they reach a cooperation equilibrium.
- (II) Herders' contribution levels under the MSS and MOS.
- (III) Cooperative herders accounting for the total number of herders under the MSS and MOS.
- (IV) The robustness of the MSS, i.e., whether the stability of the MSS is affected by exogenous variables.

Before the numerical simulation and analysis, it is necessary to briefly introduce the data source of our experiment simulation and the initial values of some variables. First, the data used in our experiment simulation are from an investigation in the Keshiketeng Banner. The Keshiketeng Banner is located in eastern Inner Mongolia and is known as the "Pearl of the grassland". It governs an area of 20,673 km² and comprises seven towns with about 2000 herders under its jurisdiction. The new MSS was explored in the Keshiketeng Banner in January 2018. We conducted field investigations in the Keshiketeng Banner regarding the income level of herders, herders' views about the MSS, herders' satisfaction and other data. Secondly, based on the investigation in the Keshiketeng Banner, this article sets the initial values of variables as follows: $N_0 = 2000$, $n_{ei0} = 5$, $r_0 = 2$, $\tau_0 = 0.1$, $V_0 = 150$, $f_{non0} = 0.15$, $R_{T_{i0}} = 50$, $\bar{\varphi}_0 = 0.5$, $\chi_0 = 0.1$ and $\omega_0 = 0.15$. When any one of the parameters is simulated, the values of other parameters remain unchanged.

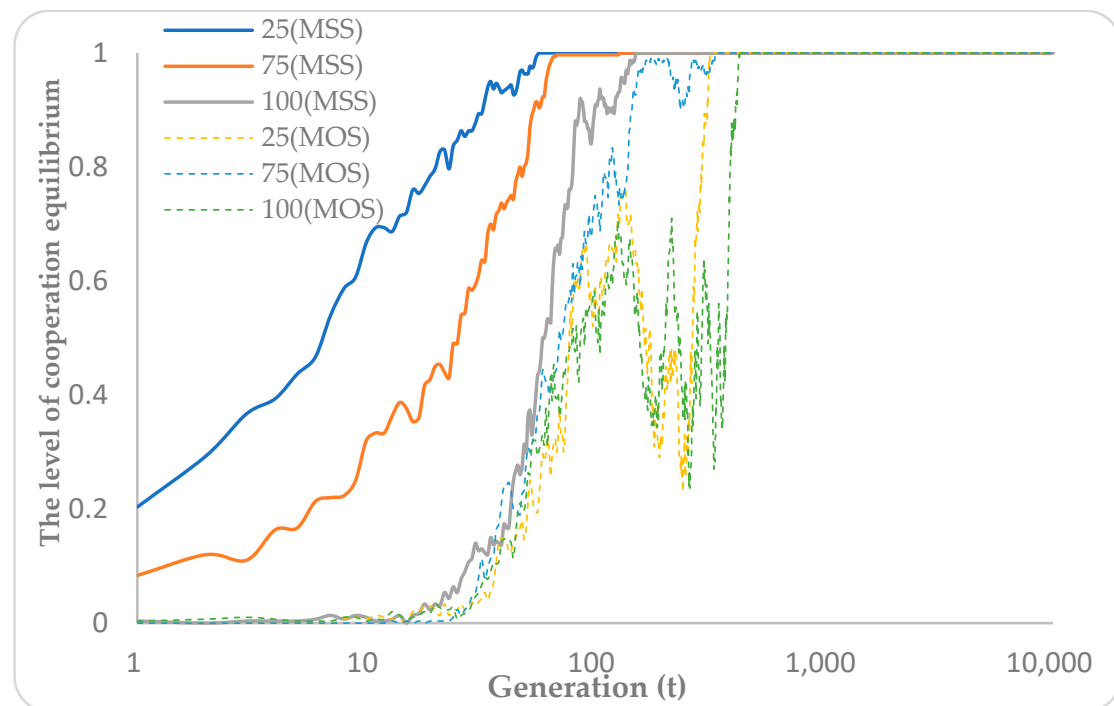
3.1. The Cooperation Level of MSS and MOS and the Speed with Which They Reach Cooperation Equilibrium

Considering the importance of four variables (R_{T_i} , φ , V and $s \cdot e$), this article uses the theoretical analysis framework shown in Figure 2 to simulate and compare the cooperation level of the MSS and MOS and the speed with which they reach a cooperation equilibrium under the influence of the four variables. The experimental simulation is iterated 10,000 times, and the results are shown in Figure 3.

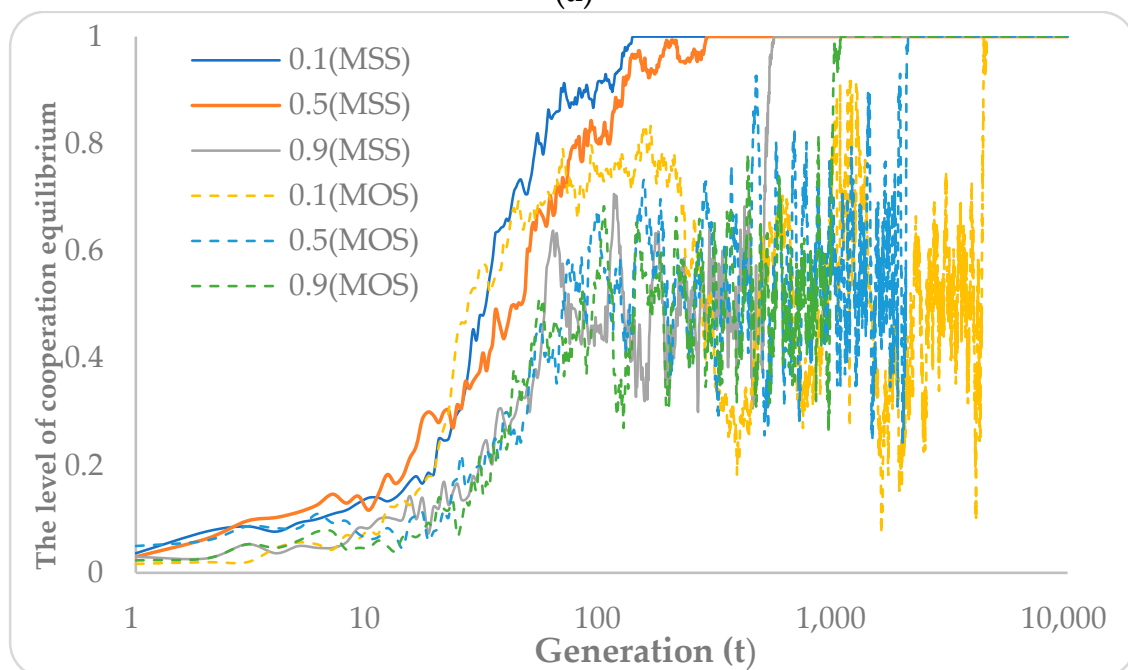
We can draw conclusions from the simulation results in Figure 3 as follows: (I) The MSS and MOS can reach the same cooperation equilibrium level. As shown in Figure 3a–d, all solid lines (which represent the MSS) and dotted lines (which represent the MOS) reach the same cooperation equilibrium level (the equilibrium level is 1) after extensive data simulation. (II) However, the MSS is faster than the MOS in reaching the cooperation equilibrium level. As shown in Figure 3a–d, all three solid lines (with represent the MSS) reach the state of cooperation equilibrium of 1 earlier than the dotted lines (which represent the MOS). (III) The smaller the reputation tolerance, R_{T_i} , and the general budget, V , the greater the satisfaction and emotion, $s \cdot e$, the earlier SGEC reaches the cooperation equilibrium. In addition, the lower the herders' income level, φ , the sooner the cooperation equilibrium is reached under the MSS, while under the MOS, the higher the herders' income level, the sooner the cooperation equilibrium is reached.

3.2. Herders' Contributions under MSS and MOS

Although the MSS can enable the cooperation equilibrium to be reached earlier, does it require more herders' contributions to achieve the cooperation equilibrium than the MOS? To determine this, it is necessary to compare herders' total contributions (TC) under the MSS and MOS. As in the previous section, this section simulates herders' total contributions in the MSS and MOS under the influence of four parameters (R_{T_i} , φ_i , V and $s \cdot e$), with solid lines and dotted lines representing the simulation results of the MSS and MOS, respectively. The simulation results are shown in Figure 4:

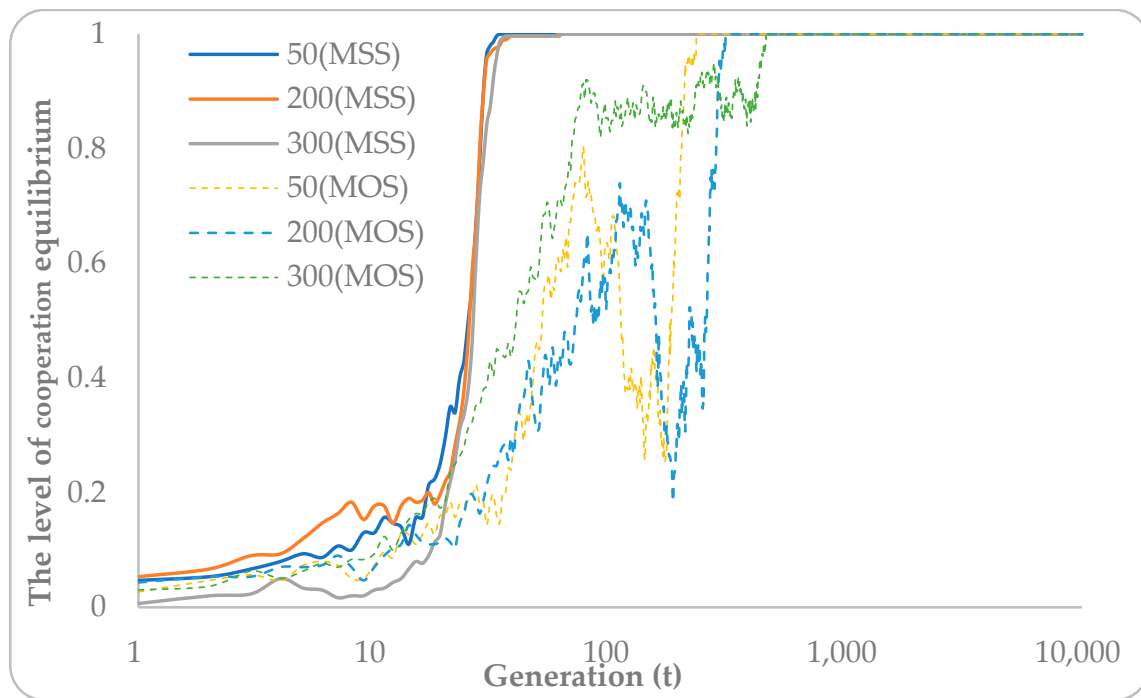


(a)

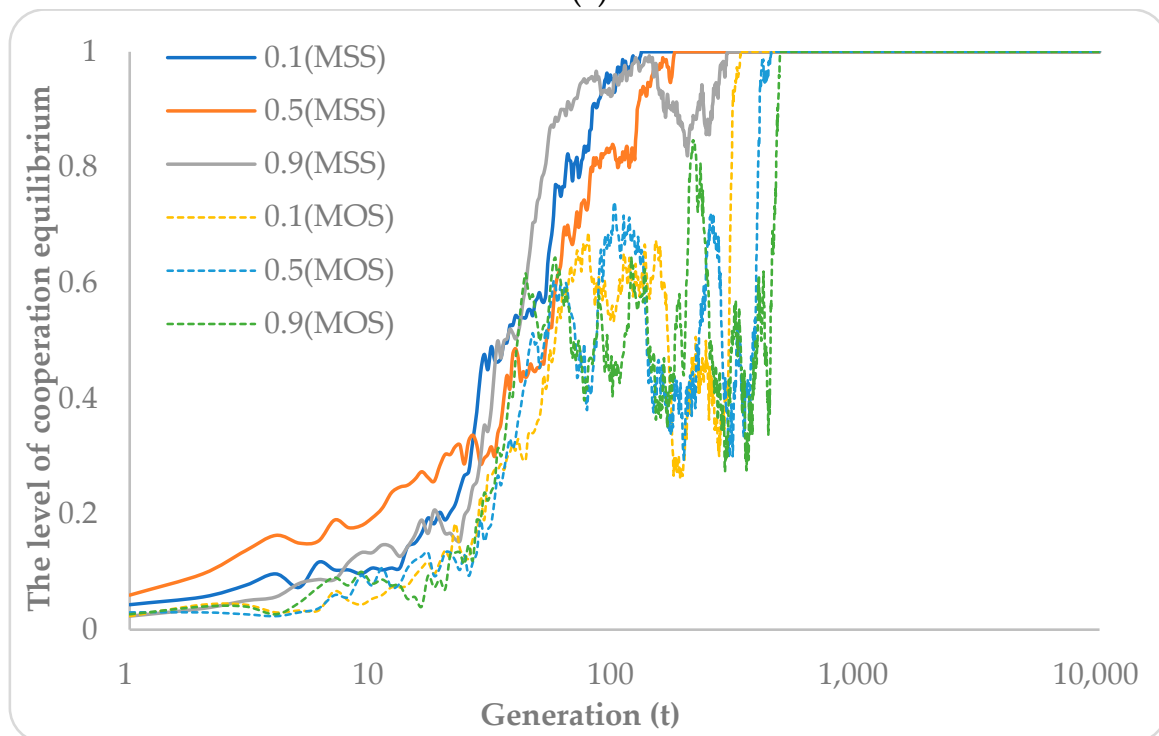


(b)

Figure 3. Cont.



(c)



(d)

Figure 3. Simulation results of the cooperation equilibrium level of MSS (shown in solid lines) and MOS (shown in dotted lines) and the speed with which they reach cooperation equilibrium under: (a) reputation tolerance ($R_T = 25, 75, 100$); (b) income level ($\varphi = 0.1, 0.5, 0.9$); (c) general budget ($V = 50, 200, 300$); and (d) satisfaction and emotion ($s \cdot e = 0.1, 0.5, 0.9$).

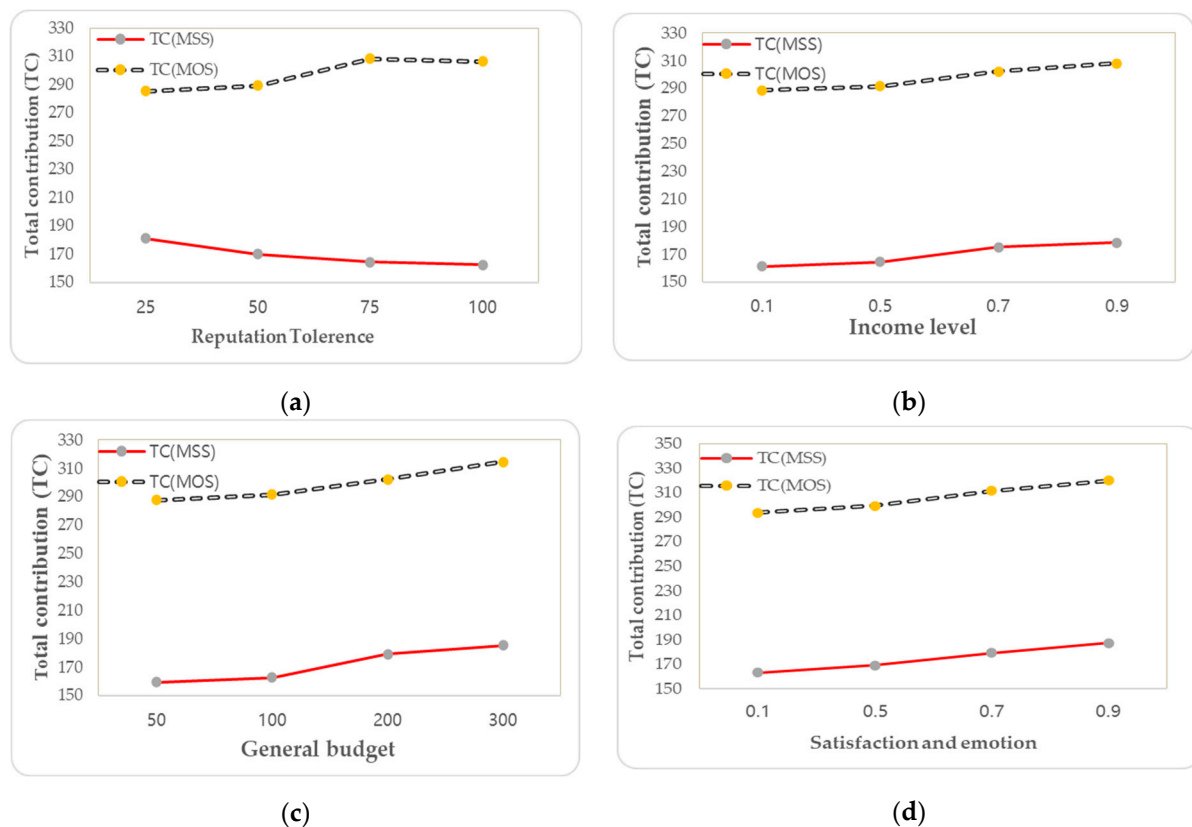


Figure 4. Simulation results of herders' total contributions in MSS (shown with solid lines) and MOS (shown with dotted lines) under: (a) reputation tolerance ($R_{T_i} = 25, 50, 75, 100$); (b) income level ($\varphi = 0.1, 0.5, 0.7, 0.9$); (c) general budget ($V = 50, 100, 200, 300$); and (d) satisfaction and emotion ($s \cdot e = 0.1, 0.5, 0.7, 0.9$).

We can draw the following conclusions from the simulation results in Figure 4: (I) Under the MSS, the herders' total amount of contributions required to achieve the cooperation equilibrium is less than that required under the MOS in SGEC. As shown in Figure 4a–d, all the solid lines (which represent the MSS) are lower than the dotted lines (which represent the MOS). (II) The higher the income level, φ , general budget, V , and satisfaction and emotion, $s \cdot e$, the more contributions herders need to make in SGEC. Meanwhile, the higher the herders' reputation tolerance, R_{T_i} , the fewer contributions herders need to make under the MSS. Under the MOS, the higher the herders' reputation tolerance, R_{T_i} , the more contributions herders need to make.

3.3. Cooperative Herders Accounting for the Total Number of Herders under MSS and MOS

We also need to determine whether the MSS can effectively mobilize more herders to participate in SGEC. Therefore, in this section, accounting for the total number of herders, we compare the ratio of cooperative herders (f) under the MSS and MOS. This section simulates how the ratio f changes under the influence of R_{T_i} , φ , V and $s \cdot e$, with solid lines and dotted lines used to represent the simulation results of the MSS and MOS, respectively. The simulation results are shown in Figure 5.

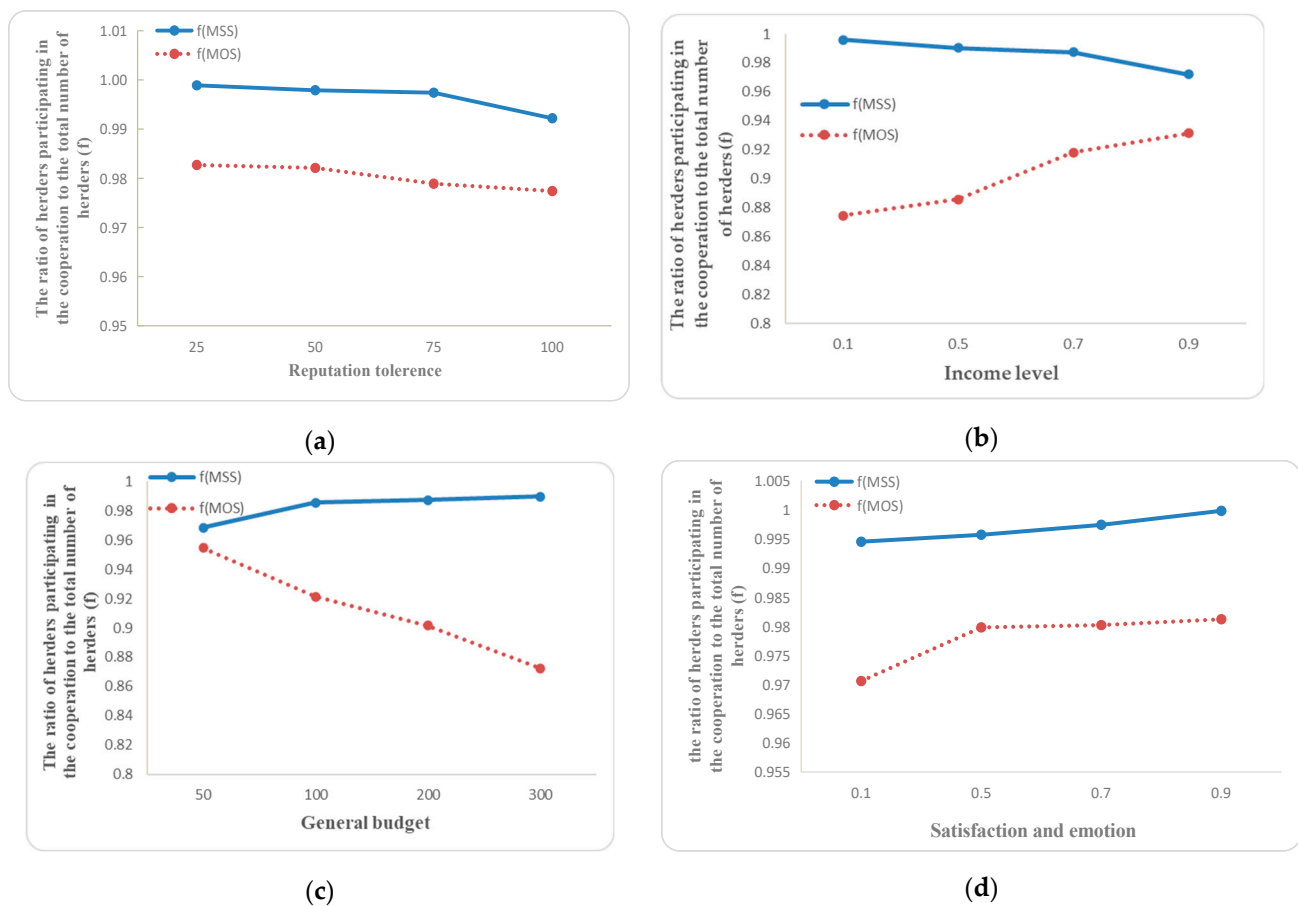
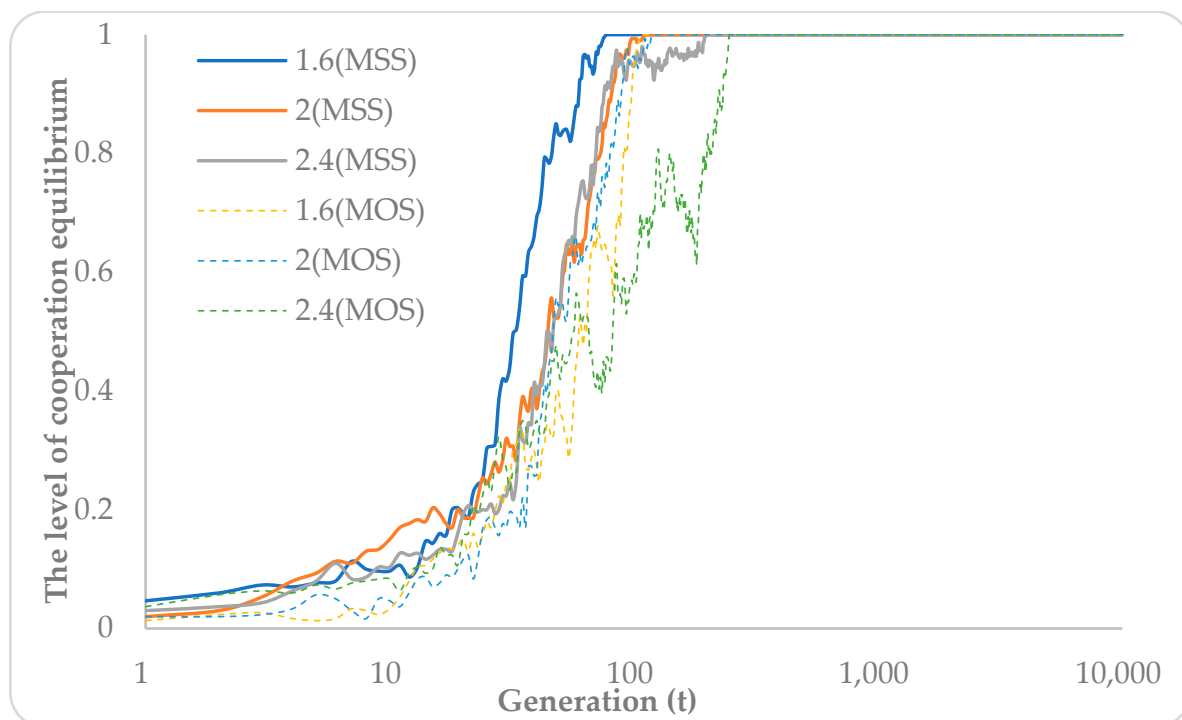


Figure 5. Simulation results of the ratio f under MSS (shown with solid lines) and MOS (shown with dotted lines) under: (a) reputation tolerance ($R_{T_i} = 25, 50, 75, 100$); (b) income level ($\varphi = 0.1, 0.5, 0.7, 0.9$); (c) general budget ($V = 50, 100, 200, 300$); and (d) satisfaction and emotion ($s \cdot e = 0.1, 0.5, 0.7, 0.9$).

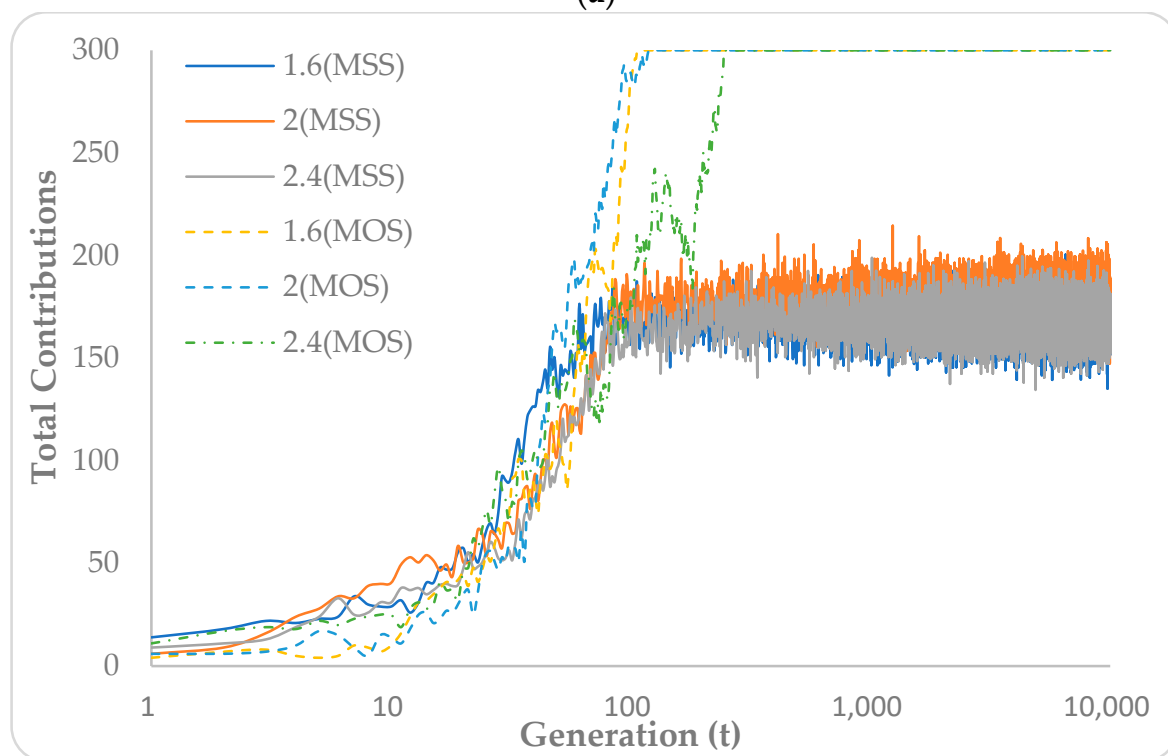
We draw the following conclusions from the simulation results in Figure 5: (I) The ratio of cooperative herders to the total number of herders under the MSS is higher than that under the MOS in SGEC. As shown in Figure 5a–d, all the solid blue lines (which represent the MSS) are above all the dotted lines (which represent the MOS). (II) The higher the income level, φ , and satisfaction and emotion, $s \cdot e$, of herders, the greater the value of this ratio under the MOS, and vice versa. Meanwhile, the higher the reputation tolerance of herders, R_{T_i} , and general budget, V , the smaller the value of this ratio f under the MOS. On the other hand, the higher the reputation tolerance of herders, R_{T_i} , and income level, φ , the smaller the value of this ratio under the MSS, while the greater the general budget, V , and satisfaction and emotion, $s \cdot e$, of herders, the greater the value of the ratio under the MSS.

3.4. The Robustness of MSS under the Exogenous Coefficients of r and τ

There are two exogenous variables in SGEC that affect the MSS: the synergy factor, r , and the amplitude of environment noise, τ . This section simulates how the level of cooperation equilibrium and herders' total contributions change with the influence of r and τ under the MSS. Additionally, we need to compare the MSS and MOS; therefore, we use solid lines and dotted lines to represent the simulation results of the MSS and MOS, respectively. The simulation results are shown in Figure 6.

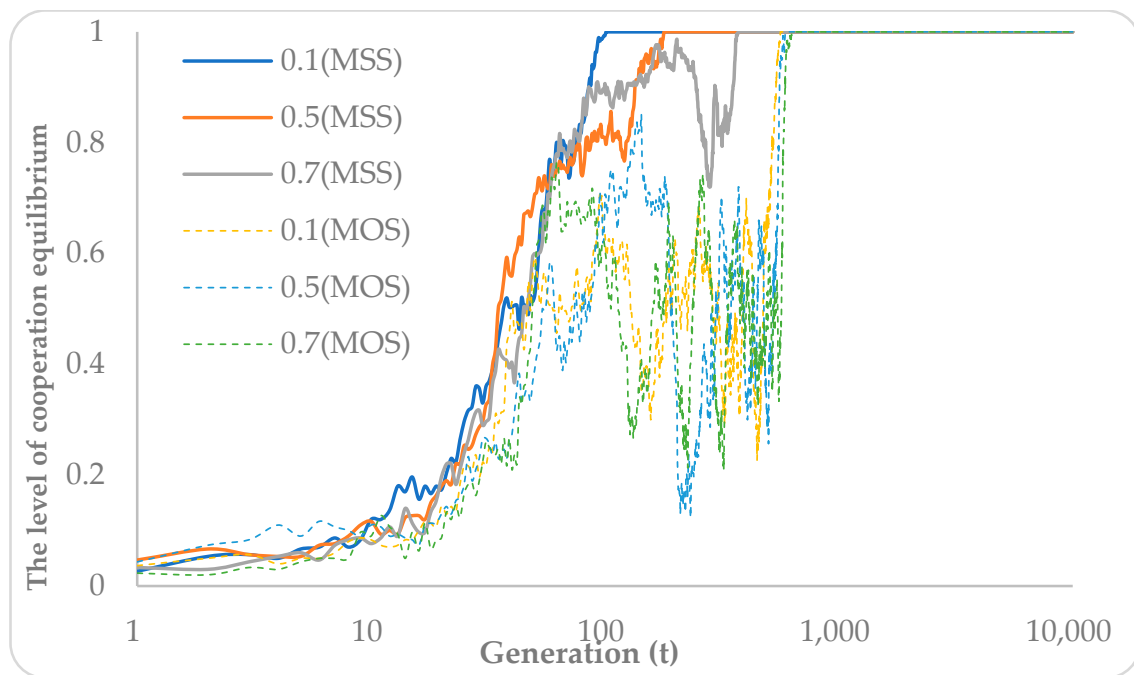


(a)

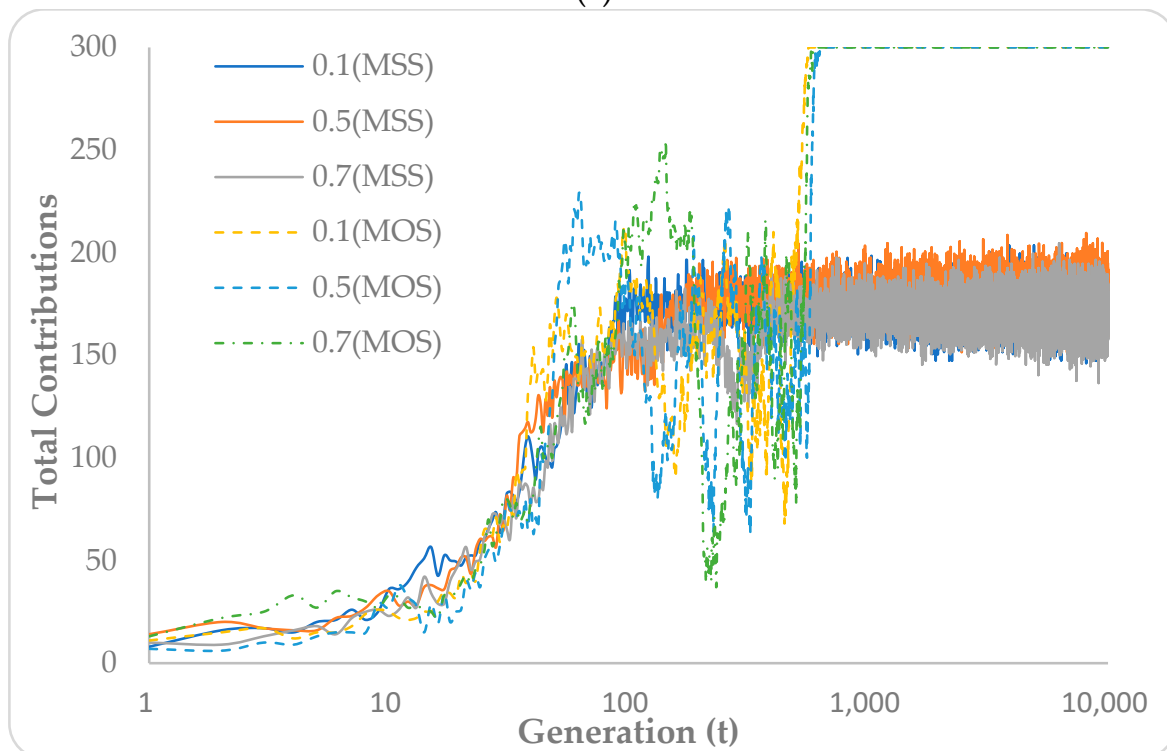


(b)

Figure 6. Cont.



(c)



(d)

Figure 6. Simulation results of the cooperation equilibrium level (a,c) and herders' total contributions (b,d) with the influence of r ($r = 1.6, 2, 2.4$) and τ ($\tau = 0.1, 0.5, 0.7$) under MSS (shown with solid lines) and MOS (shown with dotted lines) with 10,000 generations.

Figure 6a–d imply that: (I) The MSS reaches a cooperation equilibrium faster than the MOS, which is consistent with the conclusion in Section 4.1. In Figure 6a,c, all the solid lines reach a cooperation equilibrium faster than the dotted lines under the same value of r and τ , which shows that r and τ have little effect on the cooperation equilibrium of

the MSS. The cooperation equilibrium stability of the MSS is relatively high. (II) The total contributions under the MOS are higher than those under the MSS, which is consistent with the conclusion in Section 4.2. In Figure 6b,d, all the dotted lines are above the solid lines under the same value of r and τ . This shows that r and τ have little effect on the total contributions of the MSS.

3.5. Results

From this analysis, the results can be summarized as follows:

Firstly, the MSS can achieve the same cooperation equilibrium level as the MOS, and it reaches the cooperation equilibrium faster than the MOS. Therefore, the MSS can significantly improve the effectiveness of SGEC.

Secondly, not only can the MSS reach the cooperation equilibrium faster, but also, the contributions it requires from herders are far lower than those of the MOS.

Finally, the MSS can mobilize more herders to participate in SGEC and promote the emergence of cooperation. The robustness of the MSS is relatively high; it is rarely affected by exogenous coefficients.

4. Discussion

4.1. Policy Implications

Based on these experimental simulation results, it is proposed that in order to promote the application of the MSS in SGEC, governments should comprehensively adopt policies on herders' reputation tolerance, satisfaction and emotion, income levels and general budget.

First, local governments should promulgate incentive-based policies to encourage herders to set up grassland grazing mutual assistance groups and form pastoral livestock cooperatives. The research conclusions in Section 3.1 show that face culture among herders is conducive to promoting the emergence of cooperation in SGEC. Herders' face culture comes from the tight-knit nature of the acquaintance society. The commonality of herders' production and life is the basis for the formation of an acquaintance society. Therefore, grassland grazing mutual aid groups or livestock cooperatives should be set up to promote the formation of commonality in herders' production and social lives. When the livestock of any herder is negatively affected by disease or natural disasters, other herders in the same mutual aid group break from their farm work and rush to help. The relationships between herders become closer with mutual assistance, and the tight-knit nature of the acquaintance society continues to increase. In this acquaintance society, herders' sense of collective identity and the importance of their personal reputation have increased, bringing about an emphasis on personal face among herders and a decrease in their tolerance for damage to their personal reputation. If a herder does not participate in cooperation in SGEC, his/her reputation will be damaged. To maintain their reputation, the herder voluntarily cooperates in SGEC.

Secondly, local governments should work to continuously improve herders' satisfaction and emotion. The research conclusions in Sections 3.1 and 3.2 show that the higher the herders' satisfaction and emotion, the faster a cooperative equilibrium is reached using the MSS. Therefore, after the grassland's ecological restoration, local governments should encourage herders to develop green industries, transforming the ecological value of the grasslands into monetary value. This can strengthen herders' collective economy and enhance herders' satisfaction and emotion from the grassland's ecological restoration. This is exemplified in the Keshiketeng Banner in Inner Mongolia; since 2019, relying on the ecological resources of the grassland after ecological restoration, the local government of the Keshiketeng Banner has guided herders to transform traditional animal husbandry into cultural tourism, building a grassland green industry system which combines grassland ecological scenery, historical and cultural tourism, folk custom tourism and leisure vacation tourism. On the basis of economic development, herders' income levels increased substantially. Due to the economic benefits arising from voluntary cooperation in SGEC, herders' satisfaction and gain increased, which stimulates their continued participation in SGEC.

Thirdly, the Chinese central government should continuously increase financial support and increase the general budget level for SGEC. The research conclusions in Section 3.3 show that the higher the general budget, the more herders participate in SGEC. Therefore, an increase in the general budget will help encourage more herders to participate in SGEC. In China, SGEC is within the scope of local government fiscal expenditures, and the central government only provides limited assistance. Therefore, an increase in the SGEC budget would increase the financial burden of local governments. In particular, from 2020, Inner Mongolia, Tibet, Sichuan and other provinces in China have included spring grazing rest in SGEC. Undoubtedly, this will further greatly increase the SGEC's budget, and it will be difficult for local government finances to cover these costs. To ensure the sustainable development of SGEC and attract higher levels of spontaneous participation among herders, the Chinese central government should help local governments by increasing the level of budget expenditures for SGEC and reducing the financial burden on local governments through the formation of a long-term budget investment mechanism.

Finally, government financial support and the development of tourism are both external incentives to achieve the sustainable development of grasslands. However, the sustainable development of grassland ecology requires endogenous driving forces, and the concept of grassland ecological protection needs to be embedded in the hearts of herders and local governments. For example, traditional herders adhere to an ancient nomadic culture, and they value the grasslands and lakes as deities. They try to avoid overgrazing through diversified livestock grazing. Some modern herders have abandoned this value of cherishing nature; in pursuit of economic benefits, they only raise goats with high economic value, but goat grazing causes the most serious damage to the grasslands. Therefore, local governments should explore the values of traditional nomadic culture and increase the publicity of these values to implant them in the hearts of herders.

4.2. Cultural Difference

Obviously, the effectiveness of the MSS proposed in this article is based on the unique nomadic culture of the herdsmen in Inner Mongolia, China, which is significantly different from the culture of Western countries, and which will, to some extent, limit the application of the MSS.

First, common grazing in collective clan life was a traditional way of life for the herdsmen of Inner Mongolia in ancient China. The production methods and lifestyle of such common grazing has been passed down for thousands of years. In long-term grazing and life, herdsmen hold collectivism in high esteem, because it can jointly mitigate the effects of disastrous weather, livestock plague, etc., in grasslands. In the hearts of herdsmen, individuals should unconditionally serve the needs of the collective and the maximization of collective interests by sacrificing their own interests, as conditions permit. However, Western countries advocate individual freedom, and there is a strict boundary between the collective and the individual, making it difficult for individuals to obey the collective, which could make it difficult to implement the MSS.

Secondly, the key to the success of the MSS lies in using gossip and face culture to force herders to obey collective decision making. Chinese herders have adapted to collective culture and will consciously adjust their individual psychology and comply with the collective. However, in some Western countries, this can be said to be a form of social persecution, forcing individuals to obey the collective through collective pressure, which is actually not conducive to the development of the entire society. Therefore, the implementation of the MSS requires a specific cultural and social context.

4.3. Model Comparison

This article uses the PGG model to build a theoretical analysis framework for the new MSS. Compared with the traditional PGG model, the improved PGG model in this article has the following characteristics:

First, regarding the traditional PGG model, most previous works explore punishment, reward, tolerance and other strategy intervention mechanisms to mitigate “the tragedy of the commons”, while the model presented in this article does not embed these mechanisms. Instead, this strategy utilizes herders’ emphasis on reputation to promote the emergence of cooperation. The relevant government departments only need to publish a list of individuals participating in SGEC at the end of each month. Herders who are not on the list become the subject of gossip, and with the spread of gossip between herders, the herders who do not participate in cooperation feel their reputation is damaged and are forced to participate in the cooperation in SGEC. The new MSS is neither “Leviathan” nor “Privatization”, and it creates a new way for grassland herders to achieve spontaneous cooperation to protect grassland ecology. It is also consistent with “the third way” proposed by Nobel economist Elinor Ostrom on mitigating “the tragedy of the commons” [38,39].

Secondly, there are two strategies in the traditional PGG model: one cooperative strategy and one defective strategy. Based on the traditional PGG model, this article proposes an improved PGG model with two cooperative strategies and one defective strategy. In contrast to the traditional PGG model, this improved PGG model has two cooperative strategies: donating money and participation in supervision. For any herder, whether he/she chooses to donate money or participate in supervision depends on his/her income level φ_i , and herder i donates money with a probability η_i or participates in supervision with a probability $(1 - \eta_i)$. The relationship between φ_i and η_i is shown in Equation (1). The MSS designs different cooperation strategies according to herders’ income levels. The experimental simulation results show that this can encourage more herders to participate in SGEC and stimulate the collective rational growth of herders.

Thirdly, in the traditional PGG model, participants’ payoffs are fixed. However, in our improved PGG model, assuming that herders adhere to bounded rationality, their payoff cannot be fixed, and it changes with two factors: On the one hand, herders measure their payoff against the number of people (n_{ei}) in their group. If the number of people in their group is large, the total number of people participating in the distribution of the overall payoff is also large, so the payoff distributed to each participant will be relatively small. On the other hand, according to the theory of the PGG model, each participant’s payoff depends not only on his/her own contribution (c_i), but also on other participants’ contributions (c_j). If the contribution of other herders is relatively high, the herders will lower their contributions due to personal selfishness: they hope that other participants will contribute more, but they freeloader and contribute less. Under the influence of these two factors, the expression formula for herders’ payoff level is shown in Equation (6). Obviously, the herders’ payoff level is not fixed; it is inversely proportional to the number of people (n_{ei}) in the group and proportional to other participants’ contributions, but it must offset the loss of some of the participants’ own contributions.

Finally, in general, the robustness of traditional PGG models is always affected by exogenous variables, such as the synergy factor and the amplitude of environment noise. However, according to the conclusion in Section 3.4, the improved PGG model proposed here has better stability and is less affected by exogenous variables. The main reason for this is that the number of herders in the Keshiketeng Banner is small with just 2000 herders. Herders in the Keshiketeng Banner, Inner Mongolia, are actually in a “small-world” network. Watts [87] once proposed that for participants in a “small-world” network, their cooperative relationships are rarely influenced by the outside world; therefore, their relationships are relatively stable. With the increase in the number of people, the mobility of people’s interaction increases, and therefore, the stability of cooperation among people begins to be affected by exogenous variables, with the result that the robustness of the PGG model may start to decrease.

4.4. Discussion of PGG Model

The PGG model can be used to quantitatively study “the tragedy of the commons”. Considering the research on the PGG model in recent years, it can be improved in the following three aspects:

First, previous research on the PGG model focused on the emergence of cooperation among N ($N > 2$) players, with little attention to how the defective behaviors arise when cooperation is encouraged by so many policies. In the real world, governments have made many policies to encourage cooperation among people in the management of various public resources, and the main aim of PGG models is to determine how to encourage participants to cooperate. Many human behaviors continue to jeopardize collective interests, such as the destruction of public facilities, the excessive use of public resources, environmental pollution, etc. The possible reason for this is that related studies have not explored how to suppress these defective behaviors. Therefore, we need to make some changes to the PGG model so that it can be used to study how to curb defective behaviors and control freeloading for the better usage of common resources. Perhaps the non-linear representation of payoff, P_i , would be more effective. In Equation (6), the calculation formula of payoff, P_i , is linear, and r is a certain number. In fact, in the presence of defectors, r should increase with the increase in the number of cooperative participants; that is to say, the role of the cooperative coefficient is becoming increasingly prominent. Therefore, we can set a new coefficient, r^κ , instead of r ; it denotes the intrinsic growth rate of r , and κ ($\kappa > 0$) represents the changing form of r . This may expand the application of the traditional PGG model and provide a new approach to the analysis of the emergence of cooperation or the control of freeloading.

Secondly, in real society, communication between people includes both direct communication and indirect communication, but traditional PGG models usually only consider direct contact and rarely consider indirect contact among participants. In traditional PGG models, the participants’ strategic choices (as shown in Equation (2)) are influenced by their satisfaction and emotion and their neighbors who have direct contact with them. In modern society, everyone is in a social network and communicates directly or indirectly with all participants through the social network. Therefore, indirect communication with other participants also affects the strategic choices of group members. Research into the PGG model can be combined with social network theory, and the influence of indirect communication can be incorporated into the PGG model based on social network research. In recent years, many notable studies regarding social networks, such as multiplex networks, multiplayer networks, bipartite networks, etc., have been published. It has been revealed that altruism may be promoted and strengthened by complex social network communication, which will create favorable conditions for the emergence of cooperation [47,88]. Social network theory will be an effective tool for the improvement of the PGG model.

Finally, there is only one cooperative strategy (C) and one defective strategy (D) in the traditional PGG model, while in real society, the emergence of cooperation requires two or more cooperative strategies. As described in this article, there are two different cooperative strategies in SGE: donate money and participate in supervision. These two cooperative strategies can exist independently, and each can independently promote the sustainable development of grassland ecology. However, some cooperative strategies must coexist and be the same in terms of quality and quantity in order to achieve a cooperation equilibrium. For example, the realization of production requires two cooperative strategies: labor input and capital input. These two cooperative strategies must coexist and be the same in terms of quantity and quality. We use c_i^l , c_j^c , n_{ei}^l and n_{ei}^c to describe the labor contribution, the capital contribution, quantity of labor and quantity of capital, respectively. In this situation, the payoff generation function in the PGG model changes in three cases: When $n_{ei}^l < n_{ei}^c$, only $c_i^l n_{ei}^l$ can match in the cooperation equilibrium, and $c_j^c n_{ei}^c - c_i^l n_{ei}^l$ are wasted, so the effective cooperative input is $c_i^l n_{ei}^l$. When $n_{ei}^l > n_{ei}^c$, only $c_j^c n_{ei}^c$ can match in the cooperation equilibrium, and $c_i^l n_{ei}^l - c_j^c n_{ei}^c$ are wasted, so the effective cooperative

input is $c_j^c n_{ei}^c$. All the payoff generated in the cooperative equilibrium can be expressed as $P = r(c_i^l + c_j^c) \min(n_{ei}^l, n_{ei}^c)$. Therefore, the formula for the payoff function can be expressed as follows:

$$P_i = \frac{P}{\Omega_i} = \frac{r(c_i^l + c_j^c) \min(n_{ei}^l, n_{ei}^c)}{n_{ei} + 1} - c_j \quad (10)$$

Two different cooperative strategies are discussed in Equation (10), and further PGG modification models can also increase the number of different cooperative strategies to more than three.

5. Conclusions

The issue of “the tragedy of the commons” in the sustainable development of grasslands has long been a theoretical difficulty requiring investigation through quantitative modeling. This article describes a new MSS, which can be used in Inner Mongolia in the facilitation of the sustainable development of grasslands, which would help people to understand the traditional culture of Inner Mongolia in China. Furthermore, an improved PGG model is used to simulate this innovative strategy. This provides a basis for subsequent researchers to use the PGG model to simulate sustainable development issues, and it is conducive to the promotion of modeling research on sustainable development issues.

Herders in Inner Mongolia are accustomed to a gregarious life, and face culture is handed down from one generation to the next. Herders with bad reputations will be gossiped about and feel that they “lose face”. Herders not only consider their payoff, but also care about their reputation. On this basis, an improved PGG model with two cooperative strategies that considers the reputation tolerance of herders is applied in this study. We use this improved PGG model to analyze whether MSS can reach the cooperation equilibrium, and how fast it is reached. We also consider whether it is necessary for herders to make more contributions (by donating money or participating in supervision), and whether more herders can be encouraged to participate in cooperation to protect the sustainable development of grassland ecology.

Overall, a large number of experimental data simulations are performed using this model. In this paper, we compare the advantages of the MSS with the traditional strategy of paying money only (MOS), including an analysis of the cooperation equilibrium, the speed with which the cooperation equilibrium is reached, herders’ total contributions and the ratio of cooperative herders to the total number of herders. The simulation results show that the MSS can achieve the same cooperation equilibrium level as the MOS, but it reaches the cooperation equilibrium much faster; the MSS requires less money, time and human capital from herders and can mobilize more herders to participate in SGEC, which is a situation conducive to the emergence of cooperation among herders.

Further research should analyze the “relevant departments post a list of participants at the end of each month” mechanism in more detail. In the MSS used in this study, the relevant government departments publish a list of the names of cooperative herders in SGEC, but the amount of money donated by cooperative herders or the length of time they participate in supervision are not published on this list. If only the names of cooperative herders are published on the list, the information spread by gossip is incomplete and restricts the role of gossip in promoting spontaneous cooperation among herders. For example, among cooperative herders, some herders donate more money to SGEC, while some herders donate less. If the list does not disclose the amount of money donated by the cooperative herders, then the information spread by gossip will only consist of the names of herders who donate money. Herders who donate different amounts of money benefit from the same increase in reputation from the gossip, which inevitably discourages herders who donate larger amounts of money to SGEC. In addition, the relevant government departments only publish a list of cooperative herders once a month. It is unclear if this is the optimal interval, and perhaps a half-month interval or a two-month interval would be more effective. Therefore, the completeness of the information regarding the cooperative

herders in the lists and the intervals at which the lists are published will be the focus of the authors' future research.

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