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Article

Game Analysis and Simulation of the River Basin Sustainable Development Strategy Integrating Water Emission Trading

Liang Liu [1], Cong Feng [1,*], Hongwei Zhang [2,3] and Xuehua Zhang [3]

[1] College of Management and Economics, Tianjin University, Tianjin 300072, China; E-Mail: liuliang@tju.edu.cn

[2] School of Environmental Science and Engineering, Tianjin University, Tianjin 300072, China; E-Mail: zhanghw@tjpu.edu.cn

[3] School of Environmental and Chemical Engineering, Tianjin Polytechnic University, Tianjin 300387, China; E-Mail: xuehua671231@163.com

* Author to whom correspondence should be addressed; E-Mail: julia@tju.edu.cn; Tel./Fax: +86-22-2740-8780.

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Abstract: Water emission trading (WET) is promising in sustainable development strategy. However, low participation impedes its development. We develop an evolutionary game model of two enterprise populations' dynamics and stability in the decision-making behavior process. Due to the different perceived value of certain permits, enterprises choose $\boldsymbol{H}$ strategy (bidding for permit) or $\boldsymbol{D}$ strategy (not bidding). External factors are simplified according to three categories: $\boldsymbol{r_H}$-bidding related cost, $\boldsymbol{G}$-price and $\boldsymbol{F}$-penalty. Participation increase equals reaching point $(\boldsymbol{H}, \boldsymbol{H})$ in the model and is treated as an evolutionarily stable strategy (ESS). We build a system dynamics model on AnyLogic 7.1.1 to simulate the aforementioned game and draw four conclusions: (1) to reach ESS more quickly, we need to minimize the bidding related cost $\boldsymbol{r_H}$ and price $\boldsymbol{G}$, but regulate the heavy penalty $\boldsymbol{F}$; (2) an ESS can be significantly transformed, such as from $(\boldsymbol{D}, \boldsymbol{D})$ to $(\boldsymbol{H}, \boldsymbol{H})$ by regulating $\boldsymbol{r_H}$, $\boldsymbol{G}$ and $\boldsymbol{F}$ accordingly; (3) the initial choice of strategy is essential to the final result; (4) if participation seems stable but unsatisfying, it is important to check whether it is a saddle point and adjust external factors accordingly. The findings benefit both water management practice and further research.

Keywords: water allocation; river basin management; sustainable development strategy; emission trading; evolutionary game model; system dynamics simulation

1. Introduction

Along with a speedy economic growth rate, the conflict between limited resources and sustainable development is getting fiercer, which is especially reflected in current water shortages and pollution [1]. Conventional measures, such as implementing severer regulations for illegal effluent and increasing sewage charges, have not been as effective as anticipated. The main reasons are as follows [2,3]: First of all, sewage charges are far lower than pollution abatement costs so enterprises prefer paying sewage charges to reducing emissions. Secondly, local government connives with enterprises on substitute investment for eco-compensation [4]. The third is political game on privilege [5]. The conflict regarding water environment resources is extremely serious in cross-administrative river basin regions, for instance Tianjin, Beijing and Hebei province in Haihe river basin, as reported in [6].

People believe administrative means are to be blamed. In 2013, at the Third Plenary Session of 18th Communist Party of China Central Committee, the Chinese government emphasized the decisive role of market in resource allocation and advocated water emission trading (WET) as a sustainable development strategy practice [7,8]. Generally, pricing environment resources (convert external social cost to production cost) promotes enterprises making more environmental friendly decisions from a self-interest perspective [9]. Similarly, WET supplements administrative means by the invisible hand of the market [10]. Though practices occurred in Shanghai as early as 1987 [11], there has been no genuine emission trading market in China till now. Hu [12] proposed the quasi-market as a feasible solution. Furthermore, foreign practices are not perfect, as pointed out by Beall *et al.* [13] and in a property rights reversing-related study by Rabotyagov *et al.* [14].

Legally, clarification of property rights is the premise of any trading. China has developed Public Water Rights Legal Institutions, which means water resources belong to the government [15] while user rights are tradable [16], assuring the legality of WET. Another obstruction is enterprises' indifference, due to high cost and limited market scale. The present high costs are impeding potential participants from taking part, which is both cause and consequence of a limited market scale [17].

Since there is no answer for that dilemma from an endogenous perspective, we consider it in terms of the external environment and simplify the issue by determining influential conditions that will create a satisfactory result whereby potential participants prefer to bid. We develop an evolutionary game model and simulate the results by modulating critical influencing factors. The rest of the paper is organized as follows. Section 2 is a literature review on emission trading and analogous studies. Section 3 presents the evolutionary game model and is dedicated to finding a satisfactory evolutionarily stable strategy (ESS). Section 4 analyses the impact of three factors through system dynamics simulation. Section 5 draws applicable conclusions and points out further research directions.

2. Literature Review

2.1. Research Related Background

Emission trading has been associated with external diseconomy, whereby means effluent exceeds the maximum environment carrying capacity, which is detrimental to sustainability development. To deal with external diseconomy, Pigovian tax was proposed in 1920 but was found to be inefficient due to information asymmetry. In the 1960s, the concept of emission trading was put forward after Coase Theorem [18]. Then, Crocker Thomas [19] established the theoretical foundation of emission trading and Dales John [20] applied Coase Theorem in a water pollution control study.

Emission trading means using tradable emission permits instead of regulations or administrative means in pollution management. Each emission permit represents one share of water environment carrying capacity. Montgomery [21] theoretically proved the advantages of emission trading over traditional policies. Additionally, Seyyed *et al.* [22] showed the value of transferable discharge permits in practice. Hahn and Hester [23] asserted that due to internal transactions, emission trading was not saving as much costs as expected. Tietenberg [24] added that regulators' obstruction and sophisticated trading procedures were to blame for the situation. Zhang *et al.* [25] and Andrew *et al.* [26] extended the analysis of optimal scales in pollution permit markets and determined optimal trading zones. Atkinson [27] thought lack of participants was a serious problem, which is also the reason for our study.

Clarification of property rights is the premise of any trading, and emission trading is no exception. Milliman and Prince [28] illustrated that auction and taxes were impressive means. Jung and Krutilla [29] concluded that auctions offered the highest incentive. Ai [30] detailed that enterprises could be guided to choose the upper limit by setting proper lower limits in auctions. So, we adopt auctions as an initial allocation means and based on this premise, we subsequently study enterprises' behaviors.

Ning [31] asserted price should reflect seasonal assimilative capacity in rivers, which corresponds with Chen [32] of proposing to set up water rights' options exchange in river basins. Scientifically, river basins determine hydrological boundaries and are well-suited to an emissions trading study [33], as demonstrated by Fernald *et al.* [34] in their study. Combined with the real problems experienced in the Haihe river basin mentioned above, we build our simulation model in situation of enterprises sharing the same river basin.

2.2. Theoretical Approach Selection

Sun *et al.* [35] introduced the Gini coefficient. Emami Skardi *et al.* [36] applied the Nash Bargaining Theory for maximum cost saving of a participating coalition. Rebecca and Daene [37] employed Shapely in analyzing benefits' sharing and cooperation in trans-boundary river basins. Lee [38] focused on multi-objective game-theory model development for balancing economic and environmental concerns in river basin management. Nguyen *et al.* [39] applied a stochastic agent-based simulation in water quality trading with asymmetric information, uncertainty and transaction costs' research. Francisco *et al.* [40] used MFA optimization approach for pollution trading considering the sustainability of surrounding river basins. Gani and Frank [41] used institutional ecological economic framework for model governance and water pollution.

Their achievements are remarkable and research thoughts inspiring. While taking the characteristics of our research problem into thoughtful consideration, we choose evolutionary game theory as a theoretical method. This decision was made based on the following review.

As Madani [42] summarized, Game Theory plays influential role in managing water resources systems, especially in water allocation among trans-boundary users. Kicsiny *et al.* [43] applied dynamic Stackelberg game model in the study of water rationalization in drought emergency. Li [44] built non-cooperative game model between enterprises and environmental officials to study policies of preventing illegal sewage. However, traditional game theory requests a full rationality assumption, which unavoidably leads to theoretical defects; for instance, creating ambiguity on definitions of rationality which can lead to confusion [45].

In the 1980s, Maynard Smith and his *Evolution and the Theory of Games*, which originated from Darwin's biological evolution theory and Lamarckian's genetic theory, saved people from endless discussion on the perfect rationality definition. The new theory interprets social economic phenomena and predicts collective behaviors (usually a dynamic sophisticated system, in which objects' behaviors change with time) under bounded rationality assumption, which is actually more accepted by the public [46]. Besides, rationality becomes insignificant if game theory can predict behavior with conditions.

2.3. Approach Related Background

Evolutionary game theory supposes that players are randomly chosen from the population and then repeatedly play the game following biological or social rules. The equilibrium depends on their original status because the proportion of individuals taking a certain strategy in the next stage is related to the payoff in the previous stage. The behavior of each player is regulated beforehand under an evolved population distribution process. Natural selection (or market selection) causes environment adaption behavior while the external environment is given or influenced by other individuals (affected by nature as well). Thus, the optimal behavior is endogenous and depends on the behavior distribution that occurs during interactions [47]. Actually, the essence of bounded rationality is learning and the duration depends on the details in the process, shown as functions describing the equilibrium reaching process.

Chen [48] concluded that handsome reward and heavy penalty were effective through the evolutionary game model. Yu *et al.* [49] used evolutionary game theory to analyze the evolutionary process of bidding strategy of water supply enterprises from a price competition perspective. Li [50] studied ecological compensation based on evolutionary game theory and explained his theory by Taihu Basin case. On balance, most of the proposed models for water resource management are based on simple equations and can only model the allocation or pricing in the basins. Game analysis of river basin sustainable development strategy integrating WET is not common, but definitely meaningful at present. We employ evolutionary game model to represent the process of reaching desirable ESS.

The evolutionary game model we developed evolves from Hawk-Dove Game, which assumes two species fight for a kind of resource, where the value is V. The $\boldsymbol{H}$ strategy (Hawk Strategy) means the species keep fighting until injured or a rival withdraws. The $\boldsymbol{D}$ strategy (Dove Strategy) means they show off until the rival fights. If the two both choose $\boldsymbol{H}$ strategy, the game will end up with a win-lose situation. The winner gets the payment of V-C (value minus cost) and the loser win nothing. Each part has a 50%

chance to win and another 50% to lose. If $\boldsymbol{H}$ *versus* $\boldsymbol{D}$, the $\boldsymbol{H}$ part will win V for certain while the $\boldsymbol{D}$ part will get zero. In a $\boldsymbol{D}$-$\boldsymbol{D}$ situation, they will go 50-50. The payoff matrix for classical Hawk-Dove game is shown in Figure 1 [51].

		Population B	
		$\boldsymbol{H}$ **strategy**	$\boldsymbol{D}$ **strategy**
Population A	$\boldsymbol{H}$ **strategy**	$(\mathrm{V}-\mathrm{C})/2$	V
	$\boldsymbol{D}$ **strategy**	0	V/2

Figure 1. Payoff matrix for classical Hawk-Dove game.

3. Evolutionary Game Analysis

3.1. Modeling

We distinguish potential market participants as two enterprise populations, original enterprises and new comers. Generally, the former treasures water rights more than the latter due to familiarity with the local situation and potential benefit. We assume Population A represents original enterprises and Population B stands for new comers.

Population A: Enterprises that have high perceived value and more desire to bid.

Population B: Enterprises that have relative lower perceived value than Population A.

Then,

$$\boldsymbol{VA > VB} \tag{1}$$

$\boldsymbol{VA}$, $\boldsymbol{VB}$ represent perceived value of Population A and Population B, respectively.

In our model, player has same strategy set:

Strategy 1: bidding in the market, corresponding to $\boldsymbol{H}$ strategy in Hawk-Dove Game (similar to fight until injured or the rival withdraw, the player bid for the permits until out or the competitor give up)

Strategy 2: not bidding, corresponding to $\boldsymbol{D}$ strategy in Hawk-Dove Game (similar to wait and observe without take actions first)

Generally, that design bases on the original implication of Hawk-Dove Game that $\boldsymbol{H}$ strategy implies an aggressive way even paid huge sunk cost when contending for certain resources while $\boldsymbol{D}$ strategy advocates reaping without much sowing. They both have same pure strategies:

$$\boldsymbol{x_1 = y_1 = H; x_2 = y_2 = D} \tag{2}$$

Based on different perceived value, the preference to bidding is distinct. Even in one enterprise population, such as two individuals in Population A, the willingness to bid is divergent. Their mixed strategies are as follows:

$$\boldsymbol{X = (p, 1-p); Y = (q, 1-q)} \tag{3}$$

where,

$\boldsymbol{p}$ = the proportion of Population A choosing strategy 1, *i.e.*, $\boldsymbol{H}$ strategy

$\boldsymbol{1-p}$ = the proportion of Population A choosing strategy 2, *i.e.*, $\boldsymbol{D}$ strategy

$\boldsymbol{q}$ = the proportion of Population B choosing strategy 1, *i.e.*, $\boldsymbol{H}$ strategy

$\boldsymbol{1-q}$ = the proportion of Population B choosing strategy 2, *i.e.*, $\boldsymbol{D}$ strategy

Other parameters are as follows:

$\boldsymbol{r_H}$ = bidding related cost

$\boldsymbol{G}$ = unified price in a river basin

$\boldsymbol{F}$ = penalty (only if in $\boldsymbol{D}$-$\boldsymbol{D}$ situation, be punished for negative behavior. Because the original goal is participation in WET increase)

Figure 2 is a concise schematic diagram illustrating the relationship. The payoff matrix for the evolutionary game model of two enterprise populations is as shown in Figure 3.

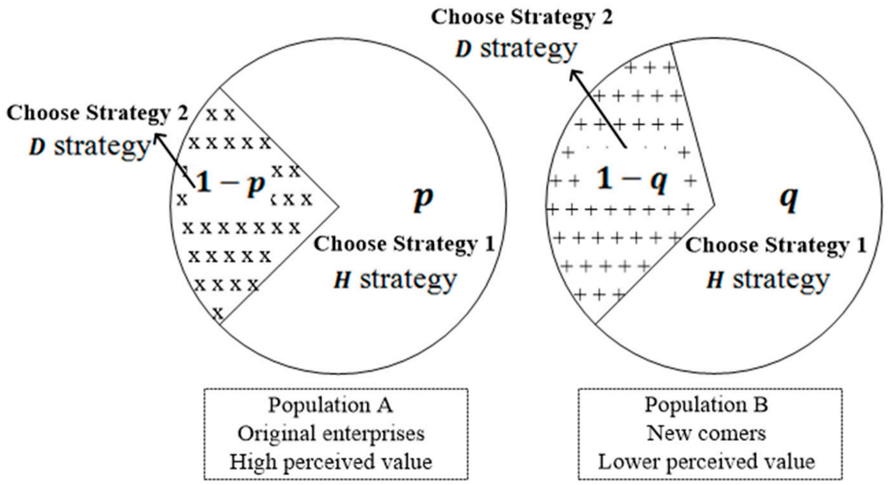

Figure 2. Schematic diagram of two enterprise populations.

			Population B	
			q	$1-q$
			Strategy 1: *H*	**Strategy 2: *D***
Population A	p	**Strategy 1: *H***	$\boldsymbol{\frac{1}{2}VA-\frac{1}{2}G-r_H, \frac{1}{2}VB-\frac{1}{2}G-r_H}$	$\boldsymbol{VA-G, 0}$
	$1-p$	**Strategy 2: *D***	$\boldsymbol{0, VB-G}$	$\boldsymbol{\frac{1}{2}VA-F, \frac{1}{2}VA-F}$

Figure 3. Payoff matrix for evolutionary game model of two enterprise populations.

The game matrixes are:

$$\boldsymbol{A}=\begin{pmatrix}\frac{1}{2}VA-\frac{1}{2}G-r_H & VA-G\\ 0 & \frac{1}{2}VA-F\end{pmatrix}, \boldsymbol{B}=\begin{pmatrix}\frac{1}{2}VB-\frac{1}{2}G-r_H & VB-G\\ 0 & \frac{1}{2}VB-F\end{pmatrix} \tag{4}$$

3.2. Results and Discussion

As for Population A,

$$E(x_1,Y)=(1,0)\begin{pmatrix}\frac{1}{2}VA-\frac{1}{2}G-r_H & VA-G\\ 0 & \frac{1}{2}VA-F\end{pmatrix}\begin{pmatrix}q\\ 1-q\end{pmatrix} \tag{5}$$

$$E(X,Y)=(p,1-p)\begin{pmatrix}\frac{1}{2}VA-\frac{1}{2}G-r_H & VA-G\\ 0 & \frac{1}{2}VA-F\end{pmatrix}\begin{pmatrix}q\\ 1-q\end{pmatrix} \tag{6}$$

Then,

$$E(x_1,Y)-E(X,Y)=(1-p)\left[\left(\frac{1}{2}G-F-r_H\right)q-(G-F-\frac{1}{2}VA)\right] \tag{7}$$

As for Population B,

$$E(y_1,X)=(1,0)\begin{pmatrix}\frac{1}{2}VB-\frac{1}{2}G-r_H & VB-G\\ 0 & \frac{1}{2}VB-F\end{pmatrix}\begin{pmatrix}p\\ 1-p\end{pmatrix} \tag{8}$$

$$E(Y,X)=(q,1-q)\begin{pmatrix}\frac{1}{2}VB-\frac{1}{2}G-r_H & VB-G\\ 0 & \frac{1}{2}VB-F\end{pmatrix}\begin{pmatrix}p\\ 1-p\end{pmatrix} \tag{9}$$

Then,

$$E(y_1,X)-E(Y,X)=(1-q)\left[\left(\frac{1}{2}G-F-r_H\right)p-(G-F-\frac{1}{2}VB)\right] \tag{10}$$

Evolutionary game theory considers evolutionary process as a dynamic system, so we build a first-order ordinary differential equation group to describe the gene adjustment replication process (*i.e.*, strategy evolutionary process), where equations are independent of time and every derivative is only about time. The ordinary differential equation group is as follows, based on Equations (7) and (10).

$$\begin{cases}\dot{p}=p(1-p)\left[\left(\frac{1}{2}G-F-r_H\right)q-(G-F-\frac{1}{2}VA)\right]\\ \dot{q}=q(1-q)\left[\left(\frac{1}{2}G-F-r_H\right)p-(G-F-\frac{1}{2}VB)\right]\end{cases} \tag{11}$$

We can get five equilibrium points based on Equation (11) = 0, *i.e.*, $\begin{cases}\dot{p}=0\\ \dot{q}=0\end{cases}$. The five points are E1$(0,0)$, E2$(0,1)$, E3$(1,1)$, E4 $(1,0)$ and E5$\left(\frac{G-F-\frac{1}{2}VB}{\frac{1}{2}G-F-r_H},\frac{G-F-\frac{1}{2}VA}{\frac{1}{2}G-F-r_H}\right)$ while satisfied $(\frac{1}{2}G-F-r_H\neq 0)$. In addition, there are several other constraint conditions that should be considered beforehand.

First of all $\begin{cases}0<p<1\\ 0<q<1\end{cases}$ is in definition, so there is a discussion on E5:

(1) If $\frac{1}{2}G-F-r_H>0$, then we get $\begin{cases}VA-G<\frac{1}{2}VA-F\\ \frac{1}{2}VA-\frac{1}{2}G-r_H>0\\ VB-G<\frac{1}{2}VB-F\\ \frac{1}{2}VB-\frac{1}{2}G-r_H>0\end{cases}$ from $\begin{cases}0<p<1\\ 0<q<1\end{cases}$;

(2) If $\frac{1}{2}\mathbf{G}-\mathbf{F}-\mathbf{r_H}<\mathbf{0}$, then we get $\begin{cases} VA-G>\frac{1}{2}VA-F \\ \frac{1}{2}VA-\frac{1}{2}G-r_H<0 \\ VB-G>\frac{1}{2}VB-F \\ \frac{1}{2}VB-\frac{1}{2}G-r_H<0 \end{cases}$ from $\begin{cases} 0<p<1 \\ 0<q<1 \end{cases}$.

We can get totally different pure strategy Nash equilibriums as Figures 4 and 5 show.

		Population B	
		Strategy 1: *H*	**Strategy 2: *D***
Population A	**Strategy 1: *H***	$\underline{\frac{1}{2}VA-\frac{1}{2}G-r_H, \frac{1}{2}VB-\frac{1}{2}G-r_H}$	$VA-G, 0$
	Strategy 2: *D*	$0, VB-G$	$\underline{\frac{1}{2}VA-F, \frac{1}{2}VA-F}$

Figure 4. Nash equilibriums. ($\frac{1}{2}\mathbf{G}-\mathbf{F}-\mathbf{r_H}>\mathbf{0}$).

		Population B	
		Strategy 1: *H*	**Strategy 2: *D***
Population A	**Strategy 1: *H***	$\frac{1}{2}VA-\frac{1}{2}G-r_H, \frac{1}{2}VB-\frac{1}{2}G-r_H$	$\underline{VA-G, 0}$
	Strategy 2: *D*	$\underline{0, VB-G}$	$\frac{1}{2}VA-F, \frac{1}{2}VA-F$

Figure 5. Nash equilibriums. ($\frac{1}{2}\mathbf{G}-\mathbf{F}-\mathbf{r_H}<\mathbf{0}$).

As mentioned above, the goal is to achieve a stable ***H*-*H*** situation, so we ignore the situation of $\frac{1}{2}G-F-r_H<0$. Then, further discussion will be under the condition of $\begin{cases} G-F-\frac{1}{2}VA>0 \\ \frac{1}{2}VA-\frac{1}{2}G-r_H>0 \\ G-F-\frac{1}{2}VB>0 \\ \frac{1}{2}VB-\frac{1}{2}G-r_H>0 \\ \frac{1}{2}G-F-r_H>0 \end{cases}$.

As Daniel Friedman [52] wrote in his paper, Jacobian matrix could help us judge local stability of equilibrium points. The Jacobian matrix is as Equation (12) shows.

$$J=\begin{pmatrix} (1-2p)\left[\left(\frac{1}{2}G-F-r_H\right)q-\left(G-F-\frac{1}{2}VA\right)\right] & p(1-p)\left(\frac{1}{2}G-F-r_H\right) \\ q(1-q)\left(\frac{1}{2}G-F-r_H\right) & (1-2q)\left[\left(\frac{1}{2}G-F-r_H\right)p-\left(G-F-\frac{1}{2}VB\right)\right] \end{pmatrix} \tag{12}$$

Then, we get the equilibrium points and their local stability as per Table 1 [53]. On the basis of Table 1, we draw the phase diagram as shown in Figure 6. The horizontal arrow shows the increase or decrease direction of $\boldsymbol{p}$ with time. The vertical arrow shows the increase or decrease direction of $\boldsymbol{q}$ with time. E1 and E3 are limit points. Specifically, E3(1,1) is the dreaming point, which represents all the potential participants choosing bidding no matter which enterprise population they belong to. From the perspective of government, the more active WET is, the more attention will be attracted to water environment sustainable development. The more participation, the larger the market scale is. Then, the contradiction aforementioned could be solved by a positive cycle. Furthermore, ESS point E3 is equipped with stability to cope with external interference and reinstates the result. The destination (ESS point E1 or E3) of the dynamic process is relevant to $\boldsymbol{p}$, $\boldsymbol{q}$ and the dynamic differential equations' PM (plus or minus) is organized in corresponding intervals, as shown in Table 1.

Table 1. Equilibrium points and local stability. ($\frac{1}{2}\mathbf{G}-\mathbf{F}-\mathbf{r_H}>\mathbf{0}$).

Equilibrium Points	Det J and Tr J	PM	Results
E1(0,0)	Det J=$\left(G-F-\frac{1}{2}VA\right)\times\left(G-F-\frac{1}{2}VB\right)$	+	ESS
	TrJ=$-\left(G-F-\frac{1}{2}VA\right)-\left(G-F-\frac{1}{2}VB\right)$	−	
E2(0,1)	Det J=$\left(\frac{1}{2}VA-\frac{1}{2}G-r_H\right)\times\left(\frac{1}{2}VB-\frac{1}{2}G-r_H\right)$	+	instable
	TrJ=$\left(\frac{1}{2}VA-\frac{1}{2}G-r_H\right)+\left(\frac{1}{2}VB-\frac{1}{2}G-r_H\right)$	+	
E3(1,1)	Det J=$\left(\frac{1}{2}VA-\frac{1}{2}G-r_H\right)\times\left(\frac{1}{2}VB-\frac{1}{2}G-r_H\right)$	+	ESS
	TrJ=$-\left(\frac{1}{2}VA-\frac{1}{2}G-r_H\right)-\left(\frac{1}{2}VB-\frac{1}{2}G-r_H\right)$	−	
E4(1,0)	Det J=$\left(G-F-\frac{1}{2}VA\right)\times\left(G-F-\frac{1}{2}VB\right)$	+	instable
	TrJ=$\left(G-F-\frac{1}{2}VA\right)+\left(G-F-\frac{1}{2}VB\right)$	+	
E5($\frac{G-F-\frac{1}{2}VB}{\frac{1}{2}G-F-r_H},\frac{G-F-\frac{1}{2}VA}{\frac{1}{2}G-F-r_H}$)	Det J=$-\frac{\left(G-F-\frac{1}{2}VA\right)\times\left(G-F-\frac{1}{2}VB\right)\times\left(\frac{1}{2}VA-\frac{1}{2}G-r_H\right)\times\left(\frac{1}{2}VB-\frac{1}{2}G-r_H\right)}{(\frac{1}{2}G-F-r_H)^2}$	−	Saddle Point
	TrJ = 0	0	

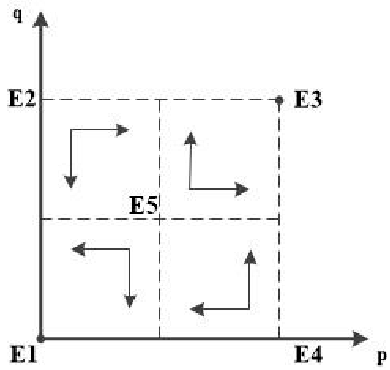

Figure 6. Phase diagram for evolutionary game model of two enterprise populations.

4. System Dynamics Simulation

4.1. Modeling and Parameter Design

We build a system dynamic (SD) model to study the dynamic behavior system of two enterprise populations when deciding on participation in WET. System dynamics is widely used in such complex situations [54], according to behavior [55] or project [56] in a system simulation, even in compartmental-spatial occasions [57]. The model system is a causally closed structure that itself defines its behavior while taking an endogenous point of view. Stave [58] studied the case of Las Vegas that SD model facilitates public understanding, and expands his understanding using four cases in another paper seven years later [59]. Winz *et al.* [60] applied SD simulation in water resources management as well. The process of encouraging market participation is a series of non-linear behaviors and the influences between variables are not surface phenomena. There is underlying issues of system structure and behavior which ask for continuous monitoring where events and decisions are blurred. Additionally, the AnyLogic 7.1.1 platform provides us a compact way to observe the causation. The mechanism involved in our model is derived from the aforementioned results in Section 3. The model consists of four stocks, two flows and seven parameters. The structure of the SD model running in AnyLogic 7.1.1 is as shown in Figure 7.

Four stocks:

$\boldsymbol{p}$ - Proportion of Population A choosing $\boldsymbol{H}$ strategy
$\boldsymbol{q}$ - Proportion of Population B choosing $\boldsymbol{H}$ strategy
$\boldsymbol{p0}$ - Proportion of Population A choosing $\boldsymbol{D}$ strategy, *i.e.*, $(\boldsymbol{1-p})$
$\boldsymbol{q0}$ - Proportion of Population B choosing $\boldsymbol{D}$ strategy, *i.e.*, $(\boldsymbol{1-q})$

Two flows:

$\boldsymbol{varA}$ - The rate of $\boldsymbol{p}$ changing with time
$\boldsymbol{varB}$ - *The rate of* $\boldsymbol{q}$ *changing with time*
The equations of $\boldsymbol{varA}$ and $\boldsymbol{varB}$ are the same as Equation (11)

Seven parameters:

$\boldsymbol{r_H}$ - Bidding related cost (unit: SC, "simulation currency", without real meaning)
$\boldsymbol{G}$ - Price (unit: SC, "simulation currency", without real meaning)
$\boldsymbol{F}$ - Penalty (unit: SC, "simulation currency", without real meaning)
$\boldsymbol{VA}$ - Perceived value of Population A (unit: SC, "simulation currency", without real meaning)
$\boldsymbol{VB}$ - Perceived value of Population B (unit: SC, "simulation currency", without real meaning)
$\boldsymbol{initialvalueOfq}$ - Initial value of $\boldsymbol{q}$
$\boldsymbol{initialvalueOfp}$ - Initial value of $\boldsymbol{p}$

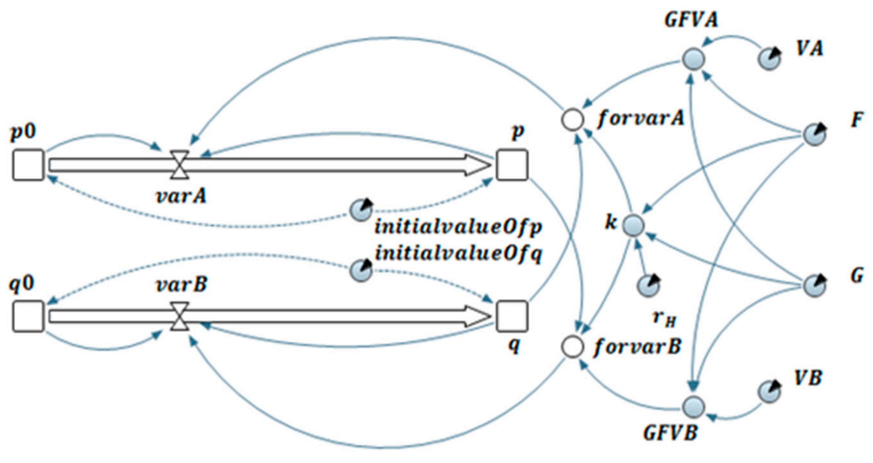

Figure 7. Model structure of SD simulation on AnyLogic 7.1.1 platform.

In Figure 7, instrumental variables include $\boldsymbol{GFVA}$, $\boldsymbol{GFVB}$, $\boldsymbol{k}$, $\boldsymbol{forvarA}$ and $\boldsymbol{forvarB}$ have no practical meaning other than facilitating the calculation process, which is necessary for the model running in AnyLogic 7.1.1.

The origin parameter setting will influence the final ESS and the rate of convergence to the stable point. Since the goal is to achieve $\boldsymbol{H}$-$\boldsymbol{H}$ equilibrium (point E3 in Figure 6) as soon as possible, the simulation will discuss the influencing factors respectively and make a combined analysis with other parameters fixed. We also take the influence of $\boldsymbol{p}$ and $\boldsymbol{q}$ into account when drawing final conclusions.

4.2. Preliminary Simulation Analysis

4.2.1. The Effect of $\boldsymbol{r_H}$ on Rate of Convergence

The values of $\boldsymbol{p}$, $\boldsymbol{q}$, $\boldsymbol{VA}$, $\boldsymbol{VB}$, $\boldsymbol{G}$ and $\boldsymbol{F}$ are fixed. Parameter setting is shown in Table 2. The units of $\boldsymbol{VA}$, $\boldsymbol{VB}$, $\boldsymbol{G}$, $\boldsymbol{F}$ and $\boldsymbol{r_H}$ are simulation currency (SC) as mentioned; their values derive from comprehensive thinking from the local government yearbook and related writings [61].

Table 2. Parameter setting of $\boldsymbol{r_H}$ effect.

Number	$\boldsymbol{p}$	$\boldsymbol{q}$	$\boldsymbol{VA}$	$\boldsymbol{VB}$	$\boldsymbol{G}$	$\boldsymbol{F}$	$\boldsymbol{r_H}$
4.2.1-1	0.9	0.7	2.1	1.9	1.2	0.1	0
4.2.1-2	0.9	0.7	2.1	1.9	1.2	0.1	0.2
4.2.1-3	0.9	0.7	2.1	1.9	1.2	0.1	0.3

The simulation results are shown in Figure 8. As $\boldsymbol{r_H}$ changes from 0–0.3, the time spent reaching ESS is longer. In other words, the smaller $\boldsymbol{r_H}$ is, the faster we get to point E3(1,1).

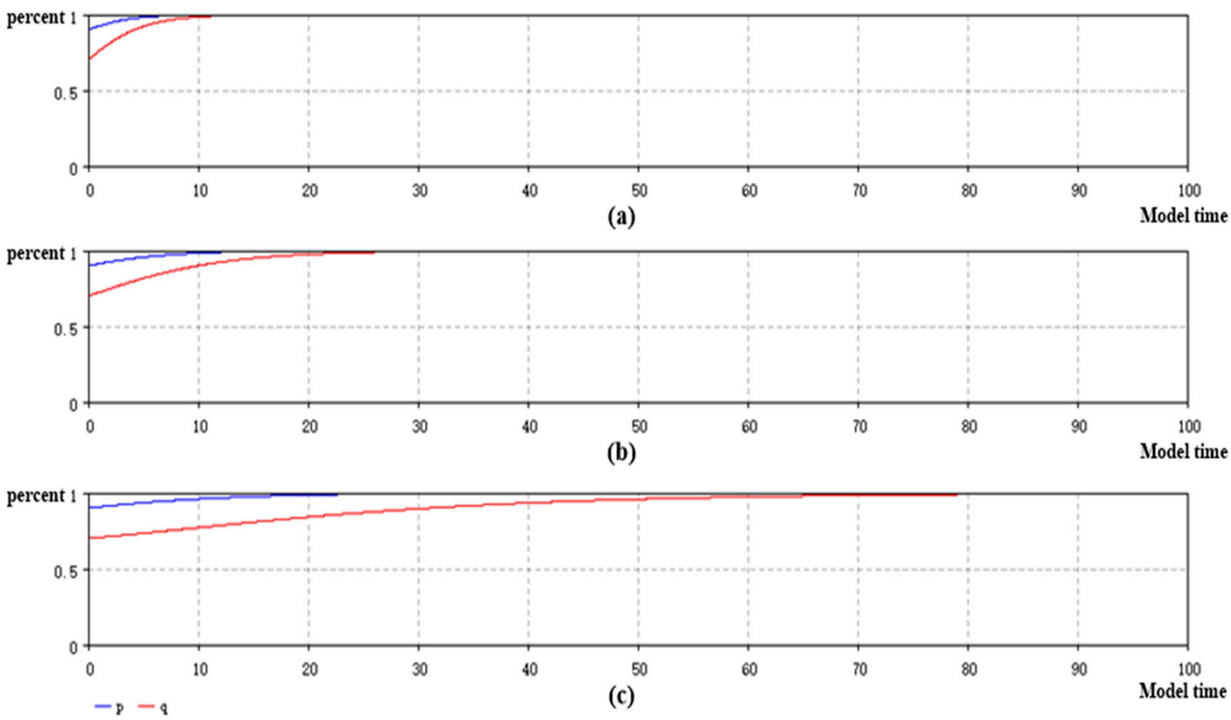

Figure 8. $\boldsymbol{r_H}$ effect on rate of convergence. (**a**) Number 4.2.1-1: $\mathbf{r_H}$ = 0; (**b**) Number 4.2.1-2: $\mathbf{r_H}$ = 0.2; (**c**) Number 4.2.1-3: $\mathbf{r_H}$ = 0.3.

4.2.2. The Effect of $\boldsymbol{G}$ on Rate of Convergence

The values of $\boldsymbol{p}$, $\boldsymbol{q}$, $\boldsymbol{VA}$, $\boldsymbol{VB}$, $\boldsymbol{F}$ and $\boldsymbol{r_H}$ are fixed. Parameter setting is shown in Table 3. The units of $\boldsymbol{VA}$, $\boldsymbol{VB}$, $\boldsymbol{G}$, $\boldsymbol{F}$ and r_H are SC. The parameter value derives from comprehensive thinking about local government yearbook and related writings [61].

Table 3. Parameter setting of $\boldsymbol{G}$ effect.

Number	$\boldsymbol{p}$	$\boldsymbol{q}$	$\boldsymbol{VA}$	$\boldsymbol{VB}$	$\boldsymbol{G}$	$\boldsymbol{F}$	$\boldsymbol{r_H}$
4.2.2-1	0.9	0.7	2.1	1.9	1.2	0.1	0.2
4.2.2-2	0.9	0.7	2.1	1.9	1.3	0.1	0.2
4.2.2-3	0.9	0.7	2.1	1.9	1.4	0.1	0.2

The simulation results are shown in Figure 9. Along with $\boldsymbol{G}$ changing from 1.2–1.4, the time spent before reaching ESS is longer. In other words, the smaller $\boldsymbol{G}$ is, the faster we get to point E3(1,1).

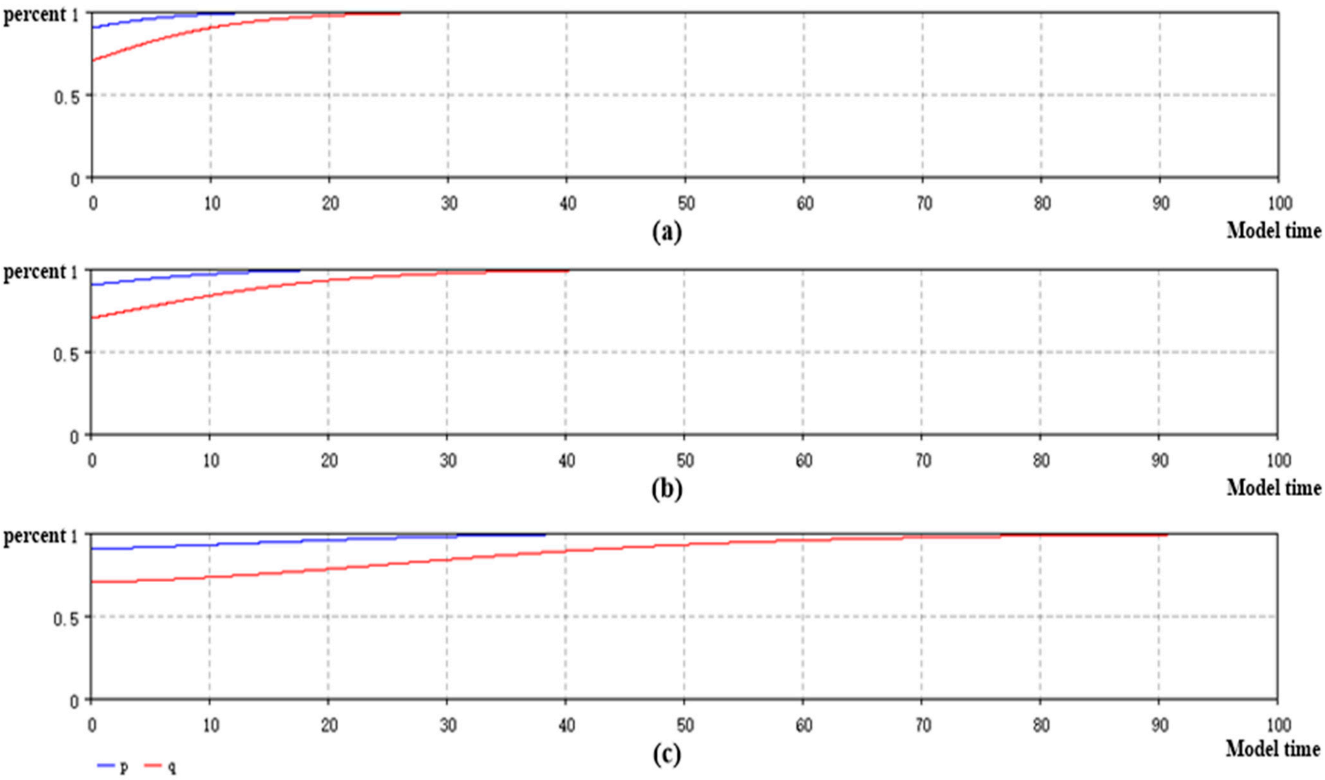

Figure 9. $\boldsymbol{G}$ effect on rate of convergence. (**a**) Number 4.2.2-1: $\boldsymbol{G}$ = 1.2; (**b**) Number 4.2.2-2: $\boldsymbol{G}$ = 1.3. (**c**) Number 4.2.2-3: $\boldsymbol{G}$ = 1.4.

4.2.3. The Effect of $\boldsymbol{F}$ on Rate of Convergence

The simulation results are shown in Figure 10, as $\boldsymbol{F}$ changes from 0–0.2, the time spent before reaching ESS is shorter. In other words, the bigger $\boldsymbol{F}$ is, the faster we get to point E3(1,1).

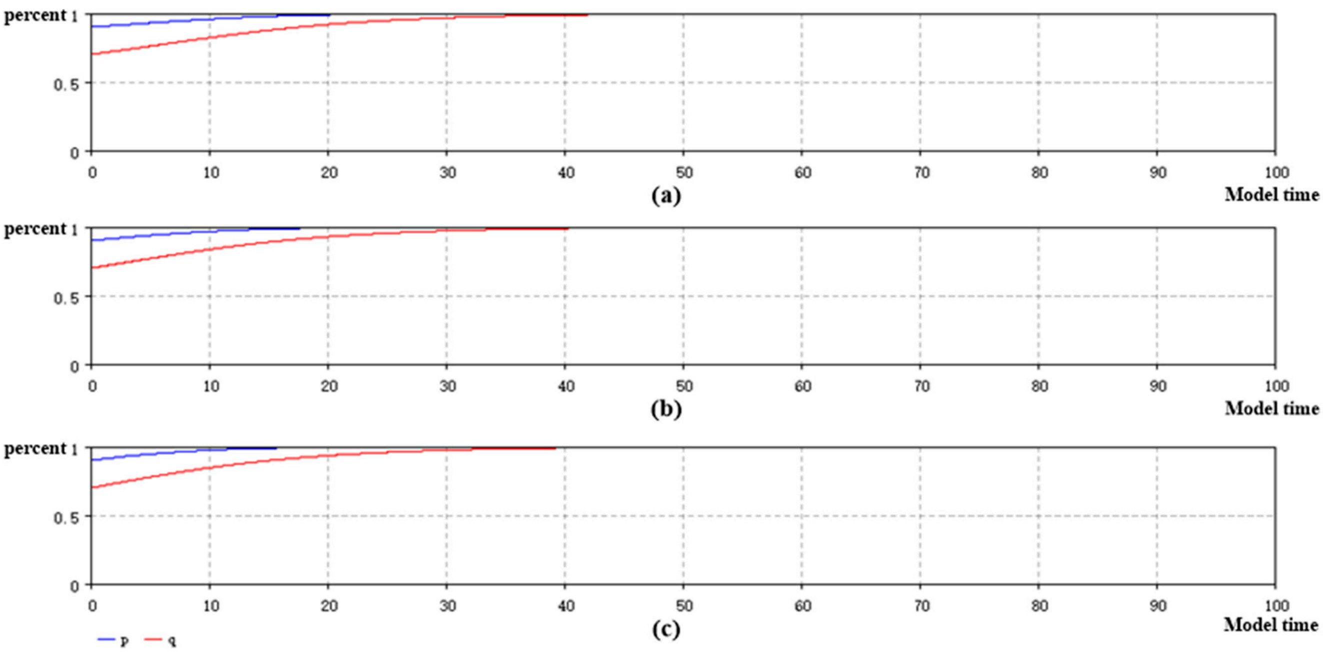

Figure 10. $\boldsymbol{F}$ effect on rate of convergence. (**a**) Number 4.2.3-1: $\boldsymbol{F}$ = 0; (**b**) Number 4.2.3-2: $\boldsymbol{F}$ = 0.1; (**c**) Number 4.2.3-3: $\boldsymbol{F}$ = 0.2.

Parameter setting is shown in Table 4 (values of $\boldsymbol{p}$, $\boldsymbol{q}$, $\boldsymbol{VA}$, $\boldsymbol{VB}$, $\boldsymbol{G}$ and $\boldsymbol{r_H}$ are fixed, units of $\boldsymbol{VA}$, $\boldsymbol{VB}$, $\boldsymbol{G}$, $\boldsymbol{F}$ and r_H are SC). The parameter value derives from comprehensive thinking from the local government yearbook and related writings [61].

Table 4. Parameter setting of $\boldsymbol{F}$ effect.

Number	p	q	VA	VB	G	F	r_H
4.2.3-1	0.9	0.7	2.1	1.9	1.3	0	0.2
4.2.3-2	0.9	0.7	2.1	1.9	1.3	0.1	0.2
4.2.3-3	0.9	0.7	2.1	1.9	1.3	0.2	0.2

4.3. Advanced Simulation Analysis

4.3.1. Test of Combined Effect of $\boldsymbol{r_H}$, $\boldsymbol{G}$ and $\boldsymbol{F}$

Based on the findings in Sections 4.2.1, 4.2.2 and 4.2.3, we test the combined effect of the three factors. We assume $\boldsymbol{p}$ = 0.2, $\boldsymbol{q}$ = 0.1, which is closer to the reality, *i.e.*, the proportion of enterprises choosing to bid is not very much. With the values of $\boldsymbol{p}$, $\boldsymbol{q}$, $\boldsymbol{VA}$, $\boldsymbol{VB}$ fixed, the units of $\boldsymbol{VA}$, $\boldsymbol{VB}$ are SC.

The simulation results are shown in Figure 11, the original situation (Number 4.3.1-1: $\boldsymbol{G}$ = 1.2, $\boldsymbol{F}$ = 0.1, $\boldsymbol{r_H}$ = 0.2) brings us an ESS of E1(0,0). To improve the situation from E1 (means $\boldsymbol{D}$- $\boldsymbol{D}$) to E3 (means $\boldsymbol{H}$-$\boldsymbol{H}$) as we anticipated, we attempt to change the value of $\boldsymbol{r_H}$, $\boldsymbol{G}, \boldsymbol{F}$ or several of them.

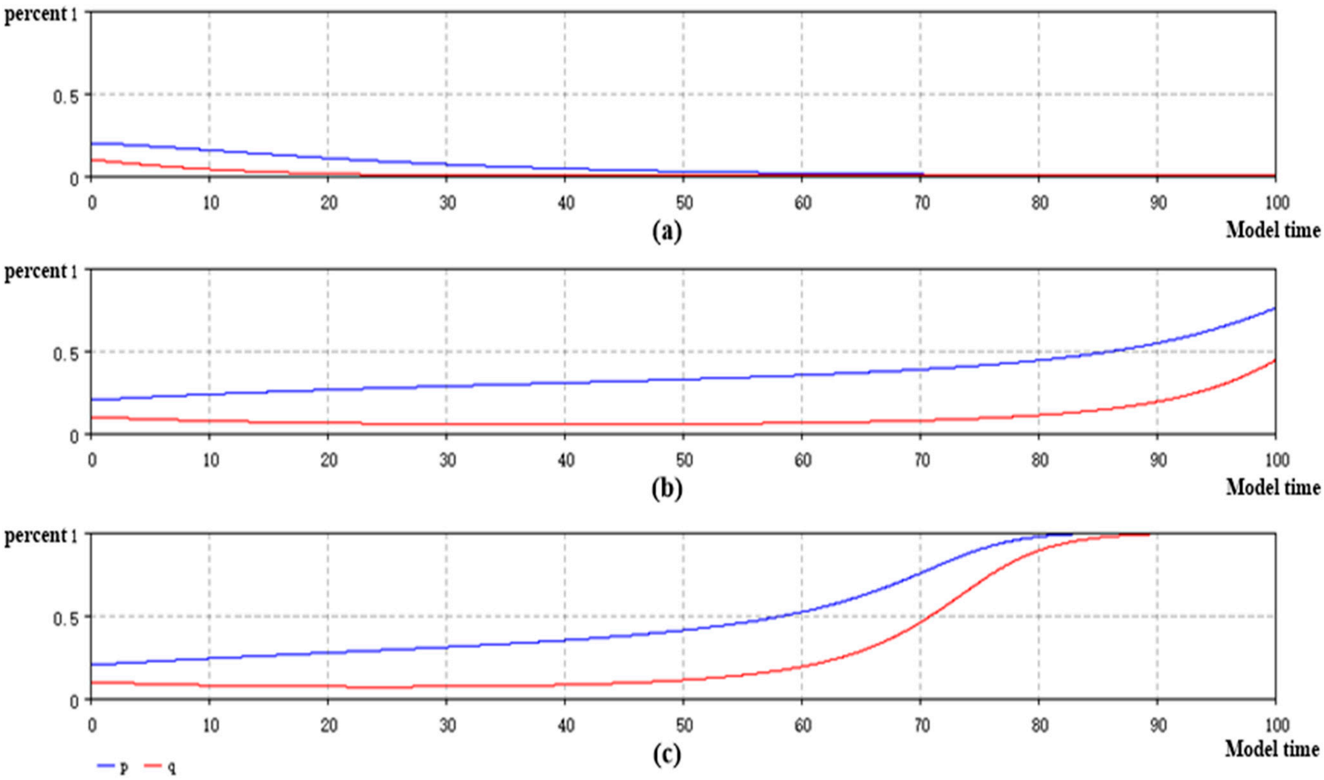

Figure 11. Combined effect of $\boldsymbol{r_H}$, $\boldsymbol{G}$ and $\boldsymbol{F}$. (**a**) Number 4.3.1-1: $\boldsymbol{G}$ = 1.2, $\boldsymbol{F}$ = 0.1 and $\boldsymbol{r_H}$ = 0.2; (**b**) Number 4.3.1-2: on contrast of 4.3.1-1, $\boldsymbol{G}$ not change, $\boldsymbol{F}$ = 0.14 and $\boldsymbol{r_H}$ = 0.1; (**c**) Number 4.3.1-3: on contrast of 4.3.1-1, $\boldsymbol{G}$ = 1.16, $\boldsymbol{F}$ not change, $\boldsymbol{r_H}$ = 0.1.

Number 4.3.1-2 shows us the trend of ESS changing from E1(0,0) to E3(1,1) and Number 4.3.1-3 proved to us ESS could be changed extensively through proper combination of initial value changing. Additionally, time spent to get to ESS E3(1,1) could be shorter as well. We can conclude that ESS could be significantly changed by proper setting of $\boldsymbol{G}$, $\boldsymbol{F}$ and $\boldsymbol{r_H}$ (the units of $\boldsymbol{G}$, $\boldsymbol{F}$ and r_H are SC).

Parameter setting is shown in Table 5.

Table 5. Parameter setting of combined effect.

Number	$\boldsymbol{p}$	$\boldsymbol{q}$	$\boldsymbol{VA}$	$\boldsymbol{VB}$	$\boldsymbol{G}$	$\boldsymbol{F}$	$\boldsymbol{r_H}$
4.3.1-1	0.2	0.1	2.1	1.9	1.2	0.1	0.2
4.3.1-2	0.2	0.1	2.1	1.9	1.2	0.14	0.1
4.3.1-3	0.2	0.1	2.1	1.9	1.16	0.1	0.1

4.3.2. Discussion of $\boldsymbol{p}$

Firstly, we discuss the difference shown in the diagram if $\boldsymbol{p}$ increases. Compared to Number 4.3.1-1, Number 4.3.2-1 has a higher $\boldsymbol{p}$ (equals 0.35), which means it took a longer time to reach ESS E1(0,0) as Figure 12 shows.

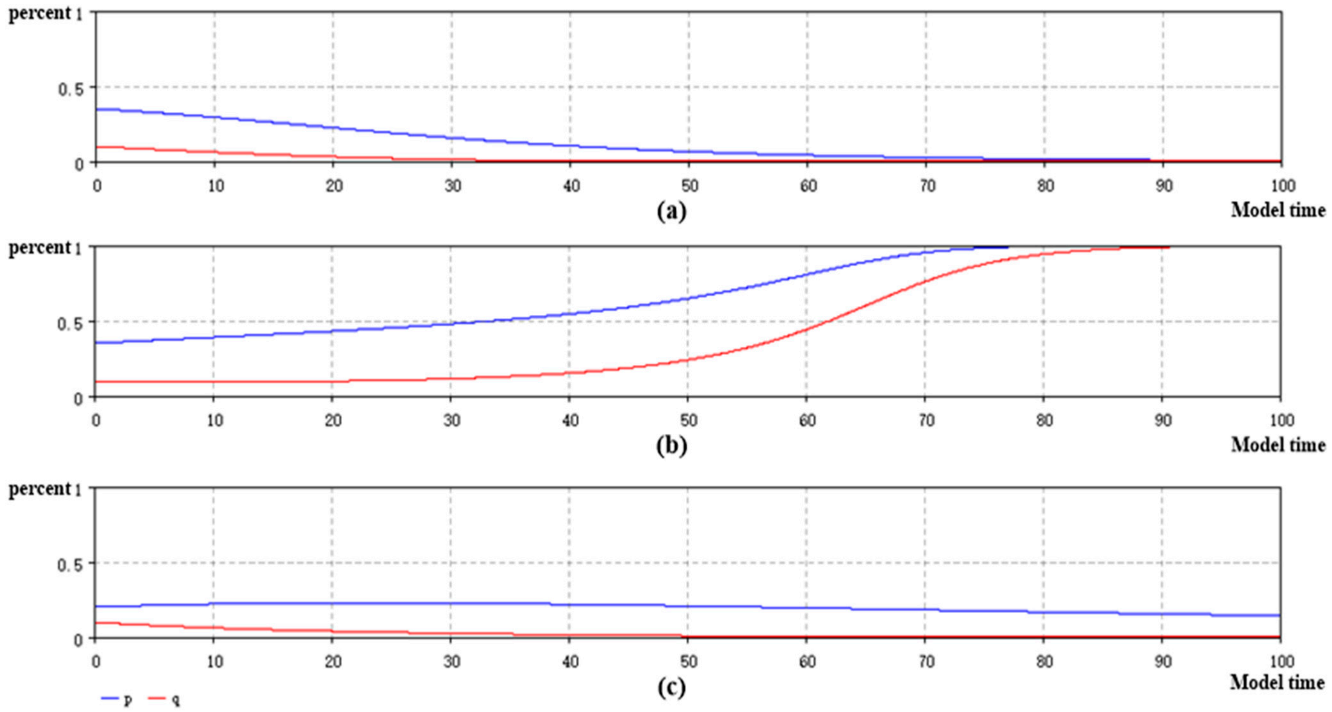

Figure 12. Influence of initial $\boldsymbol{p}$ value. (**a**) Number 4.3.2-1: on contrast of 4.3.1-1, $\boldsymbol{p}$ = 0.35; (**b**) Number 4.3.2-2: on contrast of 4.3.2-1, $\boldsymbol{G}$ = 1.16; (**c**) Number 4.3.2-3: on contrast of 4.3.1-1, $\boldsymbol{G}$ = 1.16.

Since the goal is to achieve E3(1,1), we try to change one of the three factors $\boldsymbol{G}$, $\boldsymbol{F}$ and r_H based on above conclusions (the units of $\boldsymbol{G}$, $\boldsymbol{F}$ and r_H are SC). Then, we get Number 4.3.2-2 by changing $\boldsymbol{G}$ from 1.2–1.16 in contrast to Number 4.3.2-1, which turns out to be a good choice for we finally get the ideal result for E3(1,1).

Then, we set another comparative case. Number 4.3.2-3 decreased $\boldsymbol{G}$ from 1.2 to 1.16 in contrast to Number 4.3.1-1, which tells us that simply changing one factor, such as setting a lower price, may not be helpful, so shown should be considered as a primary measure. In contrast to Number 4.3.2-2, $\boldsymbol{p}$ is decreased from 0.35 to 0.2, which did not bring us an ESS of E3(1,1). In other words, even with the same external environment (same $\boldsymbol{q}$, $\boldsymbol{VA}$, $\boldsymbol{VB}$, $\boldsymbol{r_H}$, $\boldsymbol{G}$ and $\boldsymbol{F}$. in contrast to Number 4.3.2-2), the initial value of $\boldsymbol{p}$ will cause a completely different result, which illustrates the importance of initial status of proportion of enterprises choosing bidding.

Parameter setting is summarized in Table 6.

Table 6. Parameter setting of combined effect.

Number	$\boldsymbol{p}$	$\boldsymbol{q}$	$\boldsymbol{VA}$	$\boldsymbol{VB}$	$\boldsymbol{G}$	$\boldsymbol{F}$	$\boldsymbol{r_H}$
4.3.2-1	0.35	0.1	2.1	1.9	1.2	0.1	0.2
4.3.2-2	0.35	0.1	2.1	1.9	1.16	0.1	0.2
4.3.2-3	0.2	0.1	2.1	1.9	1.16	0.1	0.2

The discussion about the effect of $\boldsymbol{q}$ is similar and we omit it here.

4.3.3. Discussion on Saddle Point

We assume $\boldsymbol{p}$ = 0.9, $\boldsymbol{q}$ = 0.7 in Number 4.2.1-1, which is actually an ideal situation where most enterprises choose bidding, as we anticipated. However, a more common situation is that not many enterprises bid in the market. So, we suppose a situation of $\boldsymbol{p}$ = 0.3, $\boldsymbol{q}$ = 0.1 as Number 4.3.3-1. The simulation results are shown in Figure 13.

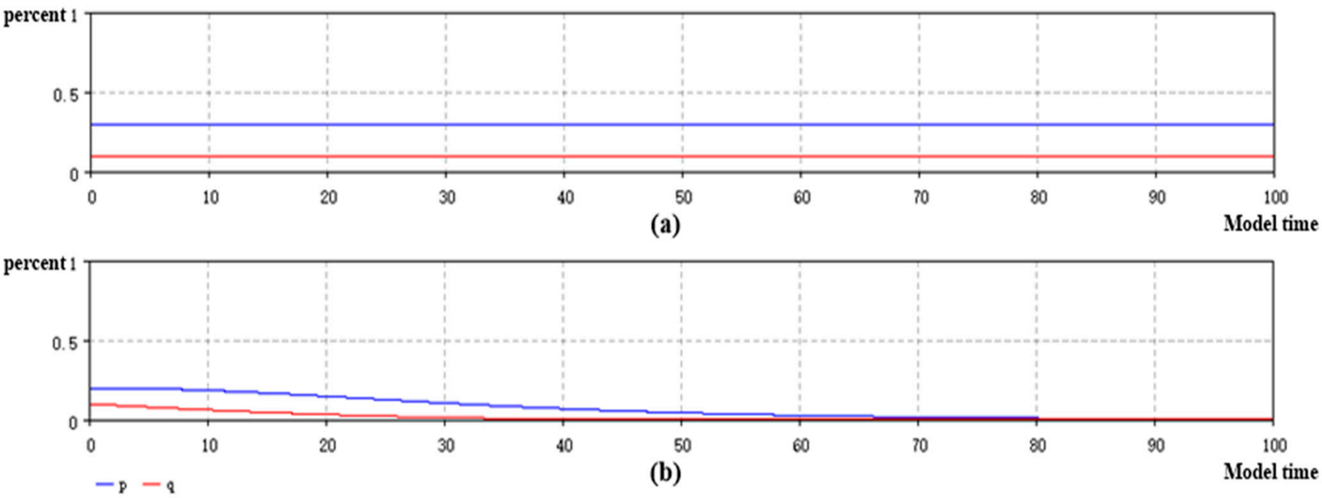

Figure 13. Utilization of saddle point characteristics. (**a**) Number 4.3.3-1: saddle point, $\boldsymbol{p}$ = 0.3, $\boldsymbol{q}$ = 0.1; (**b**) Number 4.3.3-2: $\boldsymbol{p}$ = 0.2, $\boldsymbol{q}$ = 0.1.

The curves of Number 4.3.3-1 stay as straight lines. We wonder whether it is because $\boldsymbol{p}$ and $\boldsymbol{q}$ are so minimal, so we try Number 4.3.3-2 to test. As Figure 9 shows us, the reasonable truth is not because of numerical size but due to special value. p = 0.3, q = 0.1 lead to saddle point. Though the stability of saddle point is not discussed in this paper, we could still use this knowledge to solve some problems. For instance, if the market situation seemed stable at a low participation rate, we could check whether that is a saddle point and improve the stability by changing other factors. Parameter setting is summarized in Table 7 (The units of $\boldsymbol{VA}$, $\boldsymbol{VB}$, $\boldsymbol{G}$, $\boldsymbol{F}$ and r_H are SC).

Table 7. Parameter setting of discussion on saddle point.

Number	$\boldsymbol{p}$	$\boldsymbol{q}$	$\boldsymbol{VA}$	$\boldsymbol{VB}$	$\boldsymbol{G}$	$\boldsymbol{F}$	$\boldsymbol{r_H}$
4.2.1-1	0.9	0.7	2.1	1.9	1.2	0.1	0
4.3.3-1	0.3	0.1	2.1	1.9	1.2	0.1	0
4.3.3-2	0.2	0.1	2.1	1.9	1.2	0.1	0

5. Conclusions

Essentially, water shortages and pollution are resource misallocation issues. Scarce water resources should have sufficient mobility among different industries and enterprises. Emission trading is a relatively effective way to distribute water resources and associated environment resources. However, potential participants are indifferent about joining WET. By modeling the dynamic decision process of enterprises sharing the same river basin, we find a relationship among three crucial factors that determine achieving satisfactory ESS (all enterprises choose bidding). The three factors are bidding related cost

(r_H), price (G) and penalty (F), whose mathematical relations could be applied in water management by regulatory agencies. There are four elementary conclusions: (1) to reach ESS in a shorter amount of time, we need to minimize bidding related costs r_H and price G, but regulate heavy penalties F based on simulation results; (2) an ESS could be changed extensively, such as from (D, D) to (H, H) by regulating r_H, G and F according to mathematical relations; (3) initial status of p and q is of vital importance to the final result, not only to the rate of convergence but also to the final ESS, which could be applied in water management practice; (4) if the market situation seems stable with unsatisfactory participation level, we could improve that by checking whether there is a saddle point and adjust external factors to achieve a better result. The integration of evolutionary game theory model, ESS analysis and SD simulation provides a set of parameter design rules that benefit water management practice. The government could improve the situation by regulating r_H, G and F as we have concluded. Future research could focus on determining the saddle point, which we did not discuss in detail in our study.

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Author Contributions

Liang Liu developed the original idea and contributed to the research design. Cong Feng was responsible for idea extension and processing. Hongwei Zhang contributed to the research design and provided guidance. Xuehua Zhang provided additional guidance and advice. All authors have read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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