Analysis of Tripartite Dynamic Game Theory in Ecological Law Enforcement

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Abstract. The ecological governance issues of the police department have always been urgently needed to be addressed and explored. This article will take the ecological areas of the Yangtze River Basin as an example to construct a tripartite dynamic game model between police enforcement department, fishermen and fishing enterprises and the ecology of the Yangtze River Basin. Through equilibrium point analysis and MATLAB numerical simulation, the strategic evolution process of the police department and various entities is demonstrated to demonstrate the necessity of ecological law enforcement and provide relevant suggestions.

Keywords: Tripartite Game Model, data simulation, equilibrium, decision-making.

1. Introduction

Police law enforcement behavior is carried out in a specific social environment, and the organizational form and behavior of society provide necessary prerequisites for the implementation of police law enforcement behavior [1]. The ecological side of the watershed does not have the initiative, and can only stop this behavior by promoting and providing timely feedback in hopes of law and public opinion [2], leading to a negative attitude before it is uncertain whether it can effectively stop overfishing. Police law enforcement behavior is constrained and influenced by the law enforcement environment. In addition to the standardized and orderly system design within oneself and the quality and ability of law enforcement personnel, the purification, cooperation, and support of the external law enforcement environment also play an important role [3-5]. A suitable theory is needed to find ideal strategies for these three parties.

Evolutionary game theory is an extension of traditional game theory, which focuses more on dynamic analysis and conducts research based on bounded rationality [6]. This article will construct a tripartite evolutionary game model between police law enforcement agencies, fishermen and enterprises, as well as the ecological departments in the Yangtze River Basin. In the case of limited information, the three parties in the game continuously adjust their own strategies in learning and imitation to pursue self-improvement, and choose ideal strategies through trial and error methods to achieve a dynamic equilibrium [7].

2. Construction of Tripartite Game Model

2.1. Assumptions

Assumption 1: The police department is referred to as Participant 1, fishermen and businesses are referred to as Participant 2, and the Yangtze River Basin ecological department is referred to as Participant 3.

Assumption 2: The probability of the police choosing to implement ecological law enforcement is $x(0 \le x \le 1)$, The probability of choosing not to implement ecological law enforcement is $1-x$; The probability of fishermen and businesses choosing to fish in accordance with the law is $y(0 \le y \le 1)$, The probability of choosing overfishing is $1-y$; The probability of feedback and publicity from the watershed ecological department is $z(0 \le z \le 1)$, the probability of not providing feedback on promotion is $1-z$.

Assumption 3: From the perspective of the police, when the police choose not to implement ecological law enforcement strategies, while fishermen and enterprises choose to fish according to the law, and the watershed ecology is fed back to promote the strategy, the police can obtain a series of social comprehensive benefits M_p in this situation; When the police choose to implement control strategies, the control cost required to develop and promote relevant policies is recorded as C_1. The government can record financial expenditures as F_1 and F_2, respectively, by providing economic incentives to fishermen and enterprises actively adopting cooperative strategies, as well as to the ecological sector of the watershed. In order to address the issue of overfishing, the government can obtain financial revenue by imposing additional taxes and other means, which is recorded as G. The police can also obtain long-term benefits from this control measure to promote the development of existing green ecological transformation markets, recorded as M_t. When fishermen and businesses choose overfishing strategies, the passive governance cost of the police is recorded as C_2.

Assumption 4: From the perspective of fishermen and enterprises, when the ecological department of the watershed chooses the "feedback promotion" strategy, and fishermen and enterprises choose the "overfishing" strategy, the initial return is P, Long term loss is L_1; When fishermen and businesses choose the "legal fishing" strategy, the incremental cost of scientifically implementing fishing is C_3, and the potential benefit is R_t.

Assumption 5: From the perspective of watershed ecology, when the watershed ecological department chooses the "feedback promotion" strategy and fishermen and enterprises choose the "legal fishing" strategy, the comprehensive income of the watershed ecology is W, At this point, if fishermen and enterprises choose the "overfishing" strategy, the ecological loss caused by unscientific fishing in the watershed is L_2; When the watershed ecology chooses the "no feedback promotion" strategy, and fishermen and enterprises choose to "fish according to law," both parties have zero profits. The income matrix is shown in the table below.

Table 1. Tripartite Game Benefit Matrix

Police Department	Fishermen and businesses	Ecological Department	
		Feedback promotion (z)	No feedback promotion (1-z)
Ecological law enforcement (x)	Legal fishing (y)	$M_p + M_t - C_1 - F_1 - F_2$	$-C_1$
		$P + R_t + F_1 - C$	$-C_4$
		$W + F_2$	0
	Overfishing (1-y)	$G - F_2 - C_1 - C_2$	$-C_1$
		$P - G - L_1$	0
		$W + F_2 - L_2$	0
Non ecological law enforcement (1-x)	Legal fishing (y)	M_p	0
		$P + R_t - C_3$	$-C_4$
		W	0
	Overfishing (1-y)	$-C_2$	0
		$P - L_1$	0
		$W - L_2$	0

2.2. Solving Dynamic Game Models

(1) The expected return for the police to choose the "ecological law enforcement" strategy is E_{11}, the expected return for the "non ecological law enforcement" strategy is E_{12}, and the expected return for the police department is $\overline{E_1}$:

$E_{11} = yz(M_p + M_t + C_2 - F_1 - G) + z(G - F_1 - C_2) - C_1$, $E_{12} = yz(M_p + C_2) - zC_2$

$\overline{E_1} = xE_{11} + (1-x)E_{12}$

$F(x) = x(1-x)(E_{11} - E_{12}) = x(1-x)[yz(M_t - F_1 - G) + z(G - F_1) - C_1]$

(2) The expected return for fishermen and businesses choosing the "scientific fishing" strategy is E_{21}, the expected return for choosing the "overfishing" strategy is E_{22}, and the expected return for fishermen and businesses is $\overline{E_2}$:

$E_{21} = xzF_1 + z(P + R_t - C_3 + C_4) - C_4$, $E_{22} = -xzG + z(P - L_1)$, $\overline{E_2} = yE_{21} + (1-y)E_{22}$

$F(y) = y(1-y)(E_{21} - E_{22}) = y(1-y)[xz(F_1 - G) + z(R_t - C_3 + C_4 - L_1) - C_4]$

(3) The expected return for the ecological department in the Yangtze River Basin to choose the "feedback promotion" strategy is E_{31}, the expected return for the "no feedback promotion" strategy is E_{32}, and the expected return for the ecological department in the Yangtze River Basin is $\overline{E_3}$:

$E_{31} = xF_2 - L_2 + W + yL_2$, $E_{32} = 0$, $\overline{E_3} = zE_{31} + (1-z)E_{32}$

$F(z) = z(1-z)(E_{31} - E_{32}) = z(1-z)(xF_2 + yL_2 + W - L_2)$

3. Analysis of Game Results

By substituting 8 equilibrium points into the Jacobian matrix, the eigenvalues of each equilibrium point can be obtained as shown in Table 3:

Table 2. Eigenvalues of each equilibrium point

equilibrium	eigenvalue			number
	λ_1	λ_2	λ_3	
E_1 (0, 0, 0)	$-C_1$	$-C_4$	$-W + L_2$	①
E_2 (0, 0, 1)	$G - F_2 - C$	$R_t - C_3 + L_1$	$L_2 - W$	②
E_3 (0, 1, 0)	$-C_1$	C_4	W	③
E_4 (1, 0, 0)	C_1	$-C_4$	$F_2 + W - L_2$	④
E_5 (1, 0, 1)	$C_1 + F_2 - G$	$F_1 + G + R_t - C_3 + L_1$	$L_2 - F_2 - W$	⑤
E_6 (1, 1, 0)	C_1	C_4	$F_2 + W$	⑥
E_7 (0, 1, 1)	$M_t - F_2 - F_1 - C_1$	$C_3 - L_1 - Rt$	$-W$	⑦
E_8 (1, 1, 1)	$C_1 + F_1 + F_2 - M_t$	$C_3 - F_1 - L_1 - G - R_t$	$-W - F_2$	⑧

If an evolutionary game equilibrium E is in an asymptotic stable state, then it must be a strict Nash equilibrium. And strict Nash equilibrium is also a special case of pure strategy equilibrium [8]. Therefore, for the replication dynamic system mentioned above, we only need to discuss the stability of the system at the equilibrium point. According to the Lyapunov stability theory, we can determine the asymptotic stability of the system at the equilibrium point by analyzing the eigenvalues of the system's Jacobian matrix [9]. If all eigenvalues of the Jacobian matrix $\lambda<0$, then the equilibrium point is asymptotically stable. And if there is an eigenvalue in the Jacobian matrix $\lambda>0$, then the equilibrium point is unstable [10]. Under the condition of asymptotic stability of equilibrium points, equilibrium points $E_1(0,0,0)$, $E_2(0,0,1)$, $E_5(1,0,1)$, $E_7(0,1,1)$ and $E_8(1,1,1)$ may be evolutionary stable strategies.

4. Summary

The strategic choices of the three parties under different stability conditions are different. When the law enforcement costs of the police department are high and the fines imposed on fishermen and enterprises are insufficient, the three party game subjects tend to engage in negative behavior. To

avoid this situation that is not conducive to healthy development, the long-term benefits of police law enforcement agencies, fines for overfishing by fishermen and enterprises, reduction of technological costs for scientific fishing by the public and enterprises, and losses caused by overfishing by watershed ecological departments can be improved, leading to an ideal evolution. Collaborate and drive various departments and individual entities to promote a virtuous cycle of the watershed ecological market.

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