Chinese-English Bilingual Versions for Download and Comparison

Basic Model Based on the Underlying Protocol

Based on the above discussion, this study takes the potential cooperative stability of Paleolithic tribes as a reference. Drawing on the core variables of self-interest (S) and fairness (F), the direct variables of tension (T) and elasticity(E) that buffer tension, their sub-variables, and incorporating necessary weights, nonlinear interactions, time, and environmental parameters, this study simulates and constructs a modular basic model. The model aims to characterize the operational mechanism of "underlying protocols," deepen understanding of its principles, and provide an analyzable and applicable perspective for addressing cooperation and distribution issues in real society.

Complete Functional Formula:
$B(t)=\kappa\cdot\gamma(t)\cdot SF\_bal(t)\cdot T\_ten(E,t)\cdot Env(t)$

The module decomposition is as follows:
1. Dependent Variable: B(t)
B(t) represents the "Dynamic Balance Degree" of a tribal society at time (t); $B(t) \in (0, 1]$. A higher value indicates more stable social interaction, closer to the ideal state; a lower value indicates greater tendency toward imbalance or collapse.

SF_bal(t): Core balance term of self-interest-fairness symbiosis (Self-Fairness Balance, SF_bal);
T_ten(E,t): Tension adjustment term (Tension Adjustment, T_ten), including interactively acting elasticity (E);
Env(t): Environmental disturbance term (Environmental Disturbance, Env);
$\kappa\cdot\gamma(t)$: Dynamic change term.

The values of variables or parameters involved below are simulated and need to be calibrated in practical applications.

2. Core Balance Term (Self-Fairness Balance, SF_bal)
$SF\_bal(t)=[S(t)\cdot F(t)] / [1+|S(t)-F(t)|]$

$$B\_Ps(t) = \kappa\cdot\gamma(t)\cdot SF\_Ps(t)\cdot T\_Ps(t)\cdot Ps\_Distort(t)\cdot Env(t)$$

SF_bal(t) is the "self-fairness balance term" at time t, serving as the core indicator for measuring the symbiotic state of self-interest and fairness in social interaction; $SF\_bal(t) \in (0, 1]$. It is designed to quantify the symbiotic relationship between self-interest (S) and fairness (F) and their tension on dynamic balance.

S(t): "Intensity of self-interest tendency" at time t, referring to the intensity of reasonable self-interest rather than extreme selfishness (e.g., plundering others’ interests). $S(t) \in [0, 1]$. Operational indicators include the proportion of tribal members requesting priority access to

personal labor gains or the frequency of refusing to share tools.
F(t): "Intensity of fairness perception" at time t, referring to the subjective perception of social members rather than objectively fair distribution. $F(t) \in [0, 1]$. Operational indicators include the approval rate of equal distribution schemes or the proportion of active help provided to vulnerable members.

Interpretation of the Formula:
Numerator [S(t)·F(t)]: The product of variables S(t) and F(t) at time t, representing not only the total effect of their interaction but also their symbiotic essence. Sustained social interaction cannot form or persist if only S exists without F (e.g., pure plunder) or only F exists without S (e.g., absolute egalitarianism).
Denominator [1+|S(t)-F(t)|]: Designed to effectively quantify the "degree of tension" between the two variables. The constant "1" serves as the baseline denominator in the absence of tension, ensuring the denominator is non-zero and the formula is valid. It also corresponds to the basic friction cost of social interaction(the cost of maintaining basic collaboration even without tension or destruction)when self-interest and fairness are perfectly balanced (S=F), reflecting the basic constraints of real interaction. |S(t)-F(t)| is the "absolute value of imbalance" between self-interest and fairness, quantifying the degree of tension—larger absolute values indicate stronger tension.

Key Inferences:
When S approaches 0 (self-interest is suppressed, e.g., "big pot" egalitarianism) or F approaches 0 (fairness is suppressed, e.g., individuals monopolizing prey), the numerator S·F approaches 0, the term value approaches 0, and society tends toward slack or collapse.
When S = F, the denominator is minimized (=1), and the term value is maximized ($=S^2$), reflecting perfect balance. When |S(t) - F(t)| increases (e.g., S=0.8, F=0.2), the denominator expands, the term value is weakened, society tends toward imbalance, and tension undermines cooperation.

SF_bal(t) fluctuates with tribal members' perception of rewards:

When hunting success increases (resource abundance), members' expectations for fair distribution rise (F(t) increases), and their self-interested demand for "more pay for more work" also strengthens (S(t) increases), so SF_bal(t) may remain at a high level.
When hunting failure increases (resource scarcity), members may prioritize their own security (S(t) increases), and consensus on fair distribution weakens (F(t) decreases), so |S-F| expands and SF_bal(t) decreases.

3. Tension Adjustment Term (Tension Adjustment, T_ten)
T_ten(E,t)=[RU(t)·PD(t)·HV(t)] / [1+IU(t)·DC(t)·e^(λ(t)·DC(t))]

T_ten(E,t) is the tension adjustment term of tribal society at time t, whose core function is to quantify the dynamic antagonistic relationship between Restorative Forces and Destructive Forces,and buffer the impact of Destructive Forces through elastic mechanisms(E). T_ten(E,t)∈[0, 1]. A higher term value indicates stronger suppression of Destructive Forces by Restorative Forces and more stable social balance; a lower value indicates dominant Destructive Forces and societal imbalance.

Numerator: Combination of Restorative Forces (RU·PD·HV);
Denominator: Includes the combination of Destructive Forces and an exponential term adjusted by elasticity, reflecting the nonlinear growth of Destructive Forces.

3.1 Numerator: [RU(t)·PD(t)·HV(t)]
The product of three sub-variables of Restorative Forces quantifies the total intensity of the synergistic effect of "resisting unfairness, punishing defection, and helping victims." The optimal restorative effect is achieved only when all three act together; the absence of any link weakens Restorative Forces.

Variable Symbol	Value Range	Operational Indicators (Tribal Context)	Core Function
Resisting Unfairness RU(t)	[0,1]	Proportion of members rejecting unfair distribution; frequency of protesting arbitrary distribution by authorities	Directly resist imposed unfairness, reducing the generation of Destructive Forces at the source
Punishing Defection PD(t)	[0,1]	Proportion of expelling prey embezzlers; severity of punishing slackers (e.g., reduced distribution)	Curb the spread of defection through "negative incentives," weakening the transmission chain of Destructive Forces
Helping Victims HV(t)	[0,1]	Proportion of food allocated to the elderly/weak/sick/disabled; proportion of times helping vulnerable members hunt	Reduce defection caused by resource scarcity (e.g., vulnerable members do not need to poach due to hunger), alleviating tension at the root

Example of the Numerator:
If RU=0.8 (80% of members resist unfairness), PD=0.7 (70% of defectors are punished), and HV=0.6 (60% of vulnerable members receive help) in a tribe, the total intensity of Restorative Forces = 0.8×0.7×0.6 = 0.336, indicating a strong restorative effect. If RU=0 (no one dares to resist unfairness), even if PD and HV are high, the total intensity of Restorative Forces approaches 0, and Destructive Forces will continue to expand because "social unfairness is not resisted."
3.2 Denominator: 1+IU(t)·DC(t)·e^(λ(t)·DC(t))
The combination of "baseline constant + product of Destructive Forces + exponential term" quantifies the total impact of Destructive Forces. The exponential term, adjusted by elastic mechanisms, reflects the nonlinear growth of Destructive Forces, which increases explosively beyond the threshold.

The constant "1" serves as the baseline denominator in the absence of Destructive Forces, ensuring the denominator is non-zero and corresponding to the basic friction cost of social

interaction (consistent with the denominator in SF_bal(t)).
Combination of Destructive Forces (IU(t)·DC(t)): The product of two sub-variables of Destructive Forces, reflecting the synergistic destructive effect of "imposed unfairness" and "defection and its contagion." The two reinforce each other, resulting in Destructive Forces far greater than the impact of a single variable.

Variable Symbol	Value Range	Operational Indicators (Tribal Context)	Core Function
Imposition of Unfairness IU(t)	[0,1]	Proportion of individuals claiming exclusive resources; involuntary distribution bias (e.g., dominated by powerful members)	Actively create "unfair gaps" (e.g., allocating high-quality prey only to cronies), triggering negative emotions among members
Defection and its Contagion DC(t)	[0,1]	Proportion of members embezzling prey; spread rate of slacking (e.g., from 1 to 5 people)	Defection spreads from individuals to groups, undermining cooperative trust (e.g., "one person poaching leading to group imitation")

(1) Differential Equation of Defection and its Contagion DC(t)

$$dDC(t)/dt=r\cdot DC(t)\cdot(1-DC(t)) - \zeta\cdot PD(t)\cdot DC(t) - \iota\cdot HV(t)\cdot DC(t) + \sigma_1\cdot IU(t)\cdot DC(t) + \sigma_2\cdot|S(t)-F(t)|\cdot DC(t)$$

This equation quantifies the evolutionary trend of defection over time through a structure of "growth term + inhibitory term + driving term":

Left side "dDC(t)/dt": Instantaneous change rate of defection contagion at time t (positive = spread, negative = convergence);
Right side: Terms corresponding to core factors affecting defection spread, reflecting that the natural spread of defection is inhibited by Restorative Forces and driven by Destructive Forces.

① Basic Growth Term: "r·DC(t)·(1-DC(t))"
Composed of two parts, it represents the natural spread inertia of defection, serving as the baseline term of the equation. It adopts a Logistic growth model (growth with an upper limit), consistent with the realistic constraint that defection cannot spread infinitely.

"DC(t)·(1-DC(t))": Core growth factor of defection spread. DC(t) is the current proportion of defectors (higher values = larger spread base); (1-DC(t)) is the "proportion of non-defectors" (higher values = larger potential spread space). For example:
10% defection (DC=0.1): Growth factor = 0.1×0.9 = 0.09 (large spread space);
50% defection (DC=0.5): Growth factor = 0.5×0.5 = 0.25 (peak spread rate);
90% defection (DC=0.9): Growth factor = 0.9×0.1 = 0.09 (spread space nearly saturated).
"r": Natural spread rate (r > 0, simulated value = 0.3), representing the spread efficiency of defection without intervention. If r=0.3 and current DC=0.2, the change rate of defection due to

natural spread alone = 0.3×0.2×0.8 = 0.048 (4.8% new defectors per week).

② Restorative Inhibitory Term: "$-\zeta \cdot PD(t) \cdot DC(t) - \iota \cdot HV(t) \cdot DC(t)$"
Positive intervention against defection spread, quantifying the direct suppression of defection by "punishing defection (PD(t))" and "helping victims (HV(t))". Both sub-terms are negative (inhibiting growth) and proportional to the current defection level DC(t) (more severe defection = more critical role of Restorative Forces).

"$-\zeta \cdot PD(t) \cdot DC(t)$": Inhibition of punishing defection, reflecting the direct deterrence of "negative incentives" on defection—harsher punishment = stronger inhibition. PD(t) is the intensity of punishing defection (e.g., proportion of expelling prey embezzlers, magnitude of reduced distribution); PD=0.8 means 80% of defection behaviors are punished (e.g., poachers have prey confiscated). "ζ": Punishment efficiency coefficient ($\zeta > 0$, simulated value = 0.8), measuring the inhibitory effect of punishment on defection. For example, if ζ=0.8, PD=0.7, DC=0.3: Inhibitory effect of punishment = 0.8×0.7×0.3 = 0.168 (16.8% reduction in defection spread per week).
"$-\iota \cdot HV(t) \cdot DC(t)$": Reducing defection caused by resource scarcity (e.g., the elderly/weak do not need to poach) by improving the living conditions of vulnerable members, alleviating defection motivation at the root. HV(t) is the intensity of helping victims ([0,1], e.g., proportion of food allocated to the elderly/weak, frequency of assisting vulnerable members in hunting); HV=0.6 means 60% of vulnerable members receive stable food support. "ι": Help efficiency coefficient ($\iota > 0$, simulated value = 0.5), measuring the alleviating effect of help on defection. For example, if ι=0.5, HV=0.6, DC=0.3: Inhibitory effect of help = 0.5×0.6×0.3 = 0.09 (9% reduction in defection spread per week).

③ Destructive Driving Term: "$+\sigma_1 \cdot IU(t) \cdot DC(t) + \sigma_2 \cdot |S(t)-F(t)| \cdot DC(t)$"
Negative catalysis accelerating defection spread, quantifying the stimulating effect of "imposed unfairness" and "self-fairness imbalance" on defection. Both sub-terms are positive (accelerating growth) and proportional to the current defection level DC(t) (more severe defection = stronger amplification effect of Destructive Forces).

"$+\sigma_1 \cdot IU(t) \cdot DC(t)$": Driven by imposed unfairness, reflecting the direct stimulation of artificially created unfairness on defection. Members are more likely to compensate for losses through defection (e.g., embezzlement, slacking) when distribution is obviously unfair (e.g., leaders monopolizing resources). IU(t) is the intensity of imposed unfairness (e.g., proportion of prey monopolized by leaders, distribution bias toward cronies); IU=0.7 means 70% of high-quality resources are unfairly allocated (e.g., leaders monopolize 70% of prey). "σ_1": Unfairness sensitivity coefficient ($\sigma_1 > 0$, simulated value = 0.6), measuring the catalytic effect of unfairness on defection. For example, if σ_1=0.6, IU=0.7, DC=0.3: Driving effect of unfairness=0.6×0.7×0.3= 0.126 (12.6% increase in defection spread per week).
"$+\sigma_2 \cdot |S(t)-F(t)| \cdot DC(t)$": Driven by self-fairness imbalance, reflecting the amplification effect of the gap between self-interested demand and fairness perception on defection. Excessive self-interest (S>F) or excessive fairness (F>S) can break people's expectations of reciprocity—dynamic balance between self-interest and fairness is the basis of cooperation, and imbalance undermines cooperative consensus and stimulates defection. "σ_2": Imbalance sensitivity coefficient (σ_2>0,

simulated value=0.6); |S(t)-F(t)|: Absolute value of imbalance [0,1], quantifying the tension between core independent variables of self-interest and fairness (higher values = more severe imbalance). For example, S=0.8, F=0.2: Absolute value of imbalance = 0.6, indicating self-interest is far stronger than fairness, and members tend to "take more and give less."

Trend of Defection Spread:
The final value of the instantaneous change rate "dDC(t)/dt" is determined by the above five terms, directly reflecting the real-time game trend between Restorative Forces and Destructive Forces:

If Restorative Forces > Destructive Forces (e.g., harsh punishment, adequate help, and mild unfairness): $dDC(t)/dt < 0$, defection proportion decreases, and society tends toward stability.
Example: For a tribe with current DC=0.3, r=0.3, PD=0.7, HV=0.6, IU=0.5, |S-F|=0.4:
$dDC(t)/dt = 0.3\times0.3\times0.7 - 0.8\times0.7\times0.3 - 0.5\times0.6\times0.3 + 0.6\times0.5\times0.3 + 0.6\times0.4\times0.3 = 0.063 - 0.168 - 0.09 + 0.09 + 0.072 = -0.033$ (negative value, defection proportion decreases, society stabilizes).
If Destructive Forces > Restorative Forces (e.g., absent punishment, inadequate help, and severe unfairness): $dDC(t)/dt > 0$, defection proportion increases, and society tends toward imbalance.
Threshold critical point: Assuming DC(t)=0.6 (60% of members defect). Beyond this point, even if Restorative Forces have a weak advantage, the exponential term "$e^{(\lambda(t)\cdot DC(t))}$" will amplify the instantaneous change rate "dDC(t)/dt" sharply, triggering collapse risk.

(2) Elasticity-Adjusted Exponential Term: "$e^{(\lambda(t)\cdot DC(t))}$"
Its core significance is to adjust λ(t) through elastic mechanisms (E), thereby controlling the growth rate of Destructive Forces. Stronger elasticity = smaller λ(t) = flatter exponential growth = weaker amplification effect on the denominator (i.e., buffering Destructive Forces). "e" is the natural constant (approximately 2.72 in daily calculations); "(λ(t)·DC(t))" is the exponent of the exponential function.

Elasticity Adjustment Parameter:
$\lambda(t)=\lambda_0 / [1 + E\_IC(t)\cdot E\_CE(t)\cdot E\_CS(t)]$

"λ_0": Initial threshold coefficient (simulated value = 2), representing the growth coefficient of Destructive Forces in the absence of elasticity. When E_IC = E_CE = E_CS = 0 (total elasticity failure), $\lambda(t) = \lambda_0 = 2$, and the exponential term of Destructive Forces grows the fastest.
Constant "1": Same function as in the aforementioned denominator, not repeated below.
"E_IC·E_CE·E_CS": Product of three elastic sub-variables, reflecting the synergistic buffering effect of "individual contribution, collective efficiency, and cooperative strategy." Stronger elasticity (larger product) = smaller λ(t) = slower exponential growth. For example: Elasticity product = 1 → λ=1; Elasticity product = 3 → λ=0.5.

Differential Equations of Three Elastic Sub-Variables:
All three elastic sub-variables (E_IC(t), E_CE(t), E_CS(t)) are constructed through "baseline value (constant 1) + gain term, multiplied by two inhibitory terms (product)", reflecting that elasticity is enhanced by positive factors and inhibited by Destructive Forces.

① Individual Contribution Elasticity:

$E\_IC(t)=[1 + \alpha\cdot(IC(t)/(1+IC(t)))]\cdot(1-\mu_1\cdot IU(t))\cdot(1-\mu_2\cdot DC(t)))$

Gain term $[\alpha\cdot(IC(t)/(1+IC(t)))]$: IC(t) = intensity of individual contribution [0,1] (e.g., proportion of individual hunting times); α = adjustment parameter = 0.8 (gain coefficient of contribution to elasticity). When IC approaches 1, E_IC approaches 1 + α/2 (upper limit = 1.4 when α=0.8), indicating a ceiling on tolerance.
Inhibitory terms: μ_1 = inhibition coefficient of E_IC to IU; μ_2 = inhibition coefficient of E_IC to DC. Constraints: $\mu_1, \mu_2 \in (0,1)$; simulated values: $\mu_1=0.4$, $\mu_2=0.3$. Ensuring positive values after inhibition (same for the following).

Logic: Reflects the tolerance elasticity (E) to unfairness. Greater respect for individual contribution = higher tolerance for minor unfairness (e.g., accepting "more pay for more work"), but defection weakens this tolerance.

② Collective Efficiency Elasticity:

$E\_CE(t)=[1 + \beta\cdot(CE(t)/(1+CE(t)))]\cdot(1-\nu_1\cdot IU(t))\cdot(1-\nu_2\cdot DC(t)))$

Gain term $[\beta\cdot(CE(t)/(1+CE(t)))]$: CE(t) = legitimacy of collective efficiency [0,1] (e.g., necessity of animal taming or defense); β = adjustment parameter = 1 (gain coefficient of efficiency to elasticity). When CE approaches 1, E_CE approaches 1 + β/2, indicating a ceiling on the willingness to transfer rights. For example, in an originally egalitarian tribe with fully legitimate collective goals (CE(t)≈1), individuals are willing to transfer up to 50% of private rights (consistent with the ultimatum game where the most common offer is a 50/50 split, with an average offer typically ranging from 30% to 40%（30）), close to the upper limit of 1 + β/2=1.5.
Inhibitory terms: ν_1 = inhibition coefficient of E_CE to IU; ν_2 = inhibition coefficient of E_CE to DC. Constraints: $\nu_1, \nu_2 \in (0,1)$; simulated values: $\nu_1=0.3$, $\nu_2=0.4$.

Logic: Reflects the tolerance elasticity (E) to the degree of right transfer. More legitimate collective goals = greater willingness to transfer private rights (e.g., centralized food allocation for animal taming), but defection undermines collective consensus.

③ Cooperative Strategy Elasticity:

$E\_CS(t)=[1 + \theta\cdot(CS(t)/(1+CS(t)))]\cdot(1-\xi_1\cdot IU(t))\cdot(1-\xi_2\cdot DC(t)))$

Gain term $[\theta\cdot(CS(t)/(1+CS(t)))]$: CS(t) = intensity of positive cooperative strategies [0,1] (e.g., proportion of members practicing "moderate generosity"); θ = adjustment parameter = 0.7 (gain coefficient of strategy to elasticity).
Inhibitory terms: ξ_1 = inhibition coefficient of E_CS to IU; ξ_2 = inhibition coefficient of E_CS to DC. Constraints: $\xi_1, \xi_2 \in (0,1)$; simulated values: $\xi_1=0.2$, $\xi_2=0.2$.

Logic: Reflects the buffering elasticity (E) of strategies to unfairness or defection. More prevalent cooperative strategies = easier maintenance of social interaction, but imposed unfairness directly undermines strategy effectiveness.

4. Environmental Disturbance Term (Environmental Disturbance, Env)

$Env(t) = [1/(1+\omega\_epi \times EPI(t))] \times [1/(1+\omega\_ext \times Ext\_P(t))]$

This formula quantifies the comprehensive disturbance and adaptation capacity of natural pressure (EPI) and external conflict (Ext_P). Env(t) closer to 1 indicates weaker external pressure and stronger social adaptation capacity; Env(t) closer to 0 indicates stronger external pressure disturbance.

4.1 First Part: "[1/(1+ω_epi×EPI(t))]" (Natural External Pressure Term)

Quantifies the disturbance and adaptation capacity of natural pressure (e.g., earthquakes, droughts, prey shortages) at time t. A value closer to 1 indicates smaller natural pressure and stronger adaptation capacity; a value closer to 0 indicates greater natural pressure and weaker adaptation capacity.

Numerator "1": Represents the ideal environmental state without any external pressure.

Denominator "1+ω_epi×EPI(t)": Amplifies the impact of pressure on the denominator through linear growth, ensuring an inverse correlation between pressure and the attenuation factor (greater natural pressure = larger denominator = smaller attenuation factor). The constant "1" in the denominator is the baseline value (same as the numerator), ensuring the denominator is non-zero.

4.2 Second Part: "[1/(1+ω_ext×Ext_P(t))]" (Social External Pressure Term)

Quantifies the disturbance and adaptation capacity of social pressure (e.g., external conflict) at time t. A value closer to 1 indicates smaller social external pressure and stronger adaptation capacity; a value closer to 0 indicates greater social external pressure and weaker adaptation capacity.

Numerator "1": Represents the ideal environmental state without any external pressure.

Denominator "1+ω_ext×Ext_P(t)": Amplifies the impact of pressure on the denominator through linear growth, ensuring an inverse correlation between pressure and the attenuation factor (greater social external pressure = larger denominator = smaller attenuation factor). The constant "1" in the denominator is the baseline value (same as the numerator), ensuring the denominator is non-zero.

Definition and Value of Variables/Parameters:

Parameter Symbol	Definition	Value/Simulation	Core Function (Distinguishing Natural/Social Pressure)
ω_epi	Natural pressure weight coefficient	ω_epi>0;simulated value=1.2	Amplify/reduce the disturbance of natural pressure (e.g., disasters)

Parameter Symbol	Definition	Value/Simulation	Core Function (Distinguishing Natural/Social Pressure)
EPI(t)	Natural pressure intensity (e.g., disaster level)	[0,1]	0 = no natural pressure; 1 = extreme natural pressure (e.g., major earthquake)
ω_ext	External social pressure weight coefficient	ω_ext>0;simulated value=0.8	Amplify/reduce the disturbance of social pressure (e.g., external conflict)
Ext_P(t)	External social pressure intensity(e.g.,conflict level)	[0,1]	0=no external social pressure; 1=extreme external social pressure(e.g.,full-scale war)

5. Dynamic Change Term: κ·γ(t)
This parameter adjusts the Dynamic Balance Degree (B(t)) in two ways: calibrating the magnitude difference of each module through κ to prevent B(t) from being too small or too large; and capturing the periodic fluctuation of tribal interaction through γ(t)(e.g.,seasonal resource changes, delayed punishment effects), making the model closer to the "non-static" reality of cooperation.

5.1 Calibration Coefficient”κ”
κ is the baseline calibration coefficient (κ>0, simulated value=1.2), whose core function is to balance the value magnitude of each module, coordinating the value range of the core balance term (SF_bal), tension adjustment term (T_ten), and environmental disturbance term(Env), ensuring B(t) falls within [0,1] for intuitive interpretation of "balance degree."

Example:
SF_bal≈0.5 (difficult to achieve perfect balance between S and F), T_ten≈0.3(Restorative Forces are often weaker than Destructive Forces), Env(t)≥0.4(minimum value under extreme environment). The direct product of the three ≈ 0.5×0.3×0.4=0.06 (too small to reflect differences in B(t)). After calibration with κ=1.2, the product ≈ 0.06×1.2=0.72 (still low but with more obvious differences).

5.2 Dynamic Fluctuation Factor γ(t)
γ(t) simulates the periodic fluctuation of tribal cooperation through the sine function sin(x) (value range [-1,1]), such as seasonal resource changes and delayed punishment effects.

Formula of γ(t):
$$\gamma(t)=1+\delta\cdot\sin(\omega t+\phi)$$

Constant "1": Baseline value of social cooperation fluctuation, corresponding to the stable cooperation level of the tribe without fluctuation, ensuring fluctuation does not deviate from the baseline balance.

δ:Fluctuation amplitude, δ∈(0, 0.3), simulated value = 0.2. Larger values indicate more obvious fluctuations in balance degree within a cycle (e.g.,δ=0.2 in winter=strong fluctuation; δ=0.1 in summer = weak fluctuation).
ω:Angular frequency,ω=2π/T.π is the circumference ratio (approximately 3.14 in daily calculations);T is the fluctuation period, corresponding to the time scale of fluctuation.Short period T=12,ω≈0.523 (e.g.,monthly collaboration); long period T=365, ω≈0.017 (e.g.,annual environment).
ϕ:Phase shift, ϕ∈[0, 2π), simulated value = π/2. It reflects the time delay of fluctuation (e.g., the effect of punishing defection takes 3 months to appear: delay t=ϕ/ω, ϕ=π/2 → corresponding to a 1/4 period delay).

The basic model is theoretical and applicable to micro-communities such as Paleolithic tribes or societies where the degree of power-driven self-interest tends to zero. In practical application, it needs to be refined based on specific contexts, including the addition or removal of variables and parameters, as well as the adjustment of the value ranges of variables and parameters. This model is merely intended as a "modest contribution to initiate more valuable ideas", and we hope that experts and scholars will kindly offer their insights and advice.
(If used for commercial applications, please contact the author)

基于底层协议构建的基础模型

作者：薛斌（Raphael Xue）　E-mail:xuebin1123@163.com

基于以上的探讨，本研究以旧石器时代部落可能达到的合作稳定状态为参照，基于核心变量自利（S）和公平（F），直接变量张力（T）和缓冲张力的弹性（E），以及它们的子变量，加上必要的权重、非线性交互、时间、环境参数，模拟构建一种模块化的基础模型，旨在刻画“底层协议”的运作机制，以期更深刻地理解其原理，并为应对现实社会中的合作与分配问题提供一种可分析的思路和可应用的视角。

完整函数公式：B(t)=κ • γ(t) • SF_bal(t) • T_ten(E，t) • Env(t)

模块分解如下：

一、因变量（Dependent Variable）：B(t)

B(t)是某时刻（t）某部落社会的“动态平衡度”；B(t)∈(0,1]，它的值越高，社会互动越稳定、越趋近理想状态；值越低，越趋近失衡或崩溃。其中：SF_bal(t) 是自利与公平共生的核心平衡项 (Self-Fairness Balance，SF_bal)；T_ten(E，t) 是张力调节项(Tension Adjustment，T_ten)，包含交互作用的弹性（E）；Env(t)是环境干扰项（Environmental Disturbance，Env），而κ • γ(t)是动态变化项。以下涉及的变量或参数的数值设定均为模拟，实际应用时有待校准。

二、核心平衡项 (Self-Fairness Balance，SF_bal)

SF_bal(t)=[S(t) • F(t)]/[1+|S(t)-F(t)|]

SF_bal(t)是 t 时刻的“自利-公平平衡项”，是衡量社会互动中自利与公平共生状态的核心指标；SF_bal(t)∈(0,1]，意在量化自利（S）与公平（F）的共生关系及其对动态平衡张力。其中：

S(t)是 t 时刻的“自利倾向强度”，是合理自利的强度，而不是极端的自私，如掠夺他人利益。S(t)∈[0,1]，操作化指标如部落成员请求优先获得个人劳动所得的比例或拒绝分享工具的频次）；

F(t)是 t 时刻的“公平感知强度”，指社会成员的主观感知，而不是客观的公平分配。F(t)∈[0,1]，操作化指标如成员对均等分配方案的赞同率或主动帮助弱势成员的次数占比。

其中，分子[S(t)·F(t)]是变量 S(t)和 F(t)在 t 时刻的乘积，不仅是二者共同作用的总量，更体现它们的共生本质，即仅 S 存在而 F 缺失（如纯粹掠夺），或仅 F 存在而 S 缺失（如绝对平均），均无法形成和保持可持续的社会互动；

分母[1+|S(t)-F(t)|]意在有效量化二者“张力程度”，其中的常数“1”是无张力时的基准分母，既保证分母不为 0、公式有意义，同时对应在自利与公平完全平衡（S=F）时，也对应社会互动的基础摩擦成本（即使无张力或无破坏，仍需维持基本协作的成本），项值仍能反映现实互动的基础约束；｜S(t)-F(t)｜是自利与公平的“失衡绝对值”，量化二者的张力程度，绝对值越大，张力越强。

当 S 趋向 0（自利被抑制，如大锅饭）或 F 趋向 0（公平被抑制，如个体独占猎物），分子 S·F 趋向 0，项值趋向 0，社会趋向懈怠或崩溃。

当 S=F 时，分母最小（=1），项值最大（$=S^2$），体现完全平衡；｜S(t)-F(t)｜增大时（如 S=0.8, F=0.2），分母增大，项值被削弱，趋向失衡，张力破坏合作。

SF_bal(t)随部落成员对回报的感知波动，当狩猎成功次数增加（资源丰裕）时，成员对公平分配的预期提升，则 F(t)的值上升，同时个人“多劳多得”的自利诉求也增强，则 S(t)的值上升，此时 SF_bal 的值可能维持在较高水平；当狩猎失败次数增加（资源匮乏）时，成员可能更倾向优先保障自己，则 S(t)的值上升，而公平分配的共识减弱，F(t)的值下降，此时|S-F|的值扩大，SF_bal 的值下降。

三、张力调节项 (Tension Adjustment，T_ten)

T_ten(E，t)=[RU(t)·PD(t)·HV(t)]/[1+IU(t)·DC(t)·e^(λ(t)·DC(t))]

T_ten(E，t)是 t 时刻部落社会的张力调节项，核心功能是量化修复力与破坏力的动态对抗关系，并通过弹性机制（E）缓冲破坏力的冲击。T_ten(E，t)∈[0,1]，项值越高，说明修复力对破坏力的压制越强，社会越能维持平衡；项值越低，说明破坏力占优，社会趋向失衡。其中分子是修复力组合（RU·PD·HV），分母包括破坏力组合、弹性调节的指数项。

1、分子：[RU(t)·PD(t)·HV(t)]

通过修复力的 3 个子变量的乘积，量化“抗拒不公、惩罚背叛、帮助弱势”三者协同作用的总强度，当三者共同发力，修复效果才最优；任一环节缺失，修复力都会削弱。

变量符号	取值范围	操作化指标（部落场景）	核心作用
抗拒不公 RU(t)	[0,1]	拒绝接受不公平分配的成员比例、对强权分配的抗议频次	直接抵制强加的不公平，从源头减少破坏力的产生
惩罚背叛 PD(t)	[0,1]	对私吞猎物者的驱逐比例、对偷懒者的惩戒力度（如减少分配）	通过 “负向激励” 遏制背叛行为扩散，削弱破坏力的传播链
帮助弱势 HV(t)	[0,1]	向老弱病残分配食物的比例、协助弱势成员狩猎的次数占比	减少因资源不足导致的背叛（如弱势成员不会因饥饿而偷猎），从根源缓解张力

分子示例：当部落中 RU=0.8（80%成员拒绝不公）、PD=0.7（70%背叛者被惩罚）、HV=0.6

（60%弱势成员获帮助），则修复力总强度=0.8×0.7×0.6=0.336，修复效果较强；当 RU=0，表示无人敢拒绝不公，即使 PD 和 HV 较高，修复力总强度趋向 0，破坏力也会因“社会不公不受抵制”而持续扩大。

2、分母：1+IU(t)·DC (t)·e^(λ(t)·DC (t))

通过“基础常数+破坏力乘积+指数项”，量化破坏力的总冲击，其中指数项受弹性机制的调节，体现破坏力的非线性增长特性，超过阈值后会爆发式增强。

其中常数“1”既是无破坏力时的基准分母，确保分母不为 0，也对应社会互动的基础摩擦成本（即使无张力或无破坏，仍需维持基本协作的成本）。

破坏力组合（IU (t)·DC (t)）是 2 个破坏力子变量的乘积，体现“强加不公”与“背叛传染”的协同破坏效应。两者相互强化，破坏力远大于单一变量的影响。

变量符号	取值范围	操作化指标（部落场景）	核心作用
强加的不公平 IU(t)	[0,1]	个体主张独占资源的比例、非自愿的分配倾斜（如强势成员主导）	主动制造 “不公平缺口”（如仅给亲信分配优质猎物），触发成员的负面情绪
背叛及其传染 DC(t)	[0,1]	私吞猎物的成员比例、偷懒行为的扩散速度（如从 1 人到 5 人）	背叛行为从个体蔓延至群体，瓦解合作信任（如“1 人偷猎到多人效仿”）

（1）背叛及其传染 DC(t)的微分方程：

$dDC(t)/dt=r\cdot DC(t)\cdot(1-DC(t))-\zeta\cdot PD(t)\cdot DC(t)-\iota\cdot HV(t)\cdot DC(t)+\sigma_1\cdot IU(t)\cdot DC(t)+\sigma_2\cdot|S(t)-F(t)|\cdot DC(t)$

该方程通过“增长项+抑制项+驱动项”的结构，量化背叛行为随时间的演化趋势：左侧“dDC(t)/dt”表示 t 时刻背叛传染的瞬时变化率（正值为扩散，负值为收敛），右侧各项分别对应影响背叛扩散的核心因素，整体逻辑是背叛的自然扩散趋势被修复力抑制，被破坏力驱动。

①基础增长项“r·DC(t)·(1-DC(t))”由两部分组成，表示背叛的自然扩散惯性，这是方程的基准项，体现背叛行为在无任何干预时的自发演化规律，采用 Logistic 增长模型（有上限的增长），符合背叛不可能无限扩散的现实约束。其中：

“DC(t)·(1 - DC(t))”是背叛扩散的核心增长因子，DC(t)是当前背叛比例（值越高，扩散基础越大），(1-DC(t))是“未背叛者比例”（值越高，潜在扩散空间越大），如当部落中 10%的人背叛(DC=0.1)，增长因子=0.1×0.9=0.09（扩散空间大）；当 50%的人背叛(DC=0.5)，增长因子 = 0.5×0.5=0.25（扩散速度峰值）；当 90%的人背叛（DC=0.9），增长因子 = 0.9×0.1=0.09（扩散空间接近饱和）。

“r”是自然扩散速率（r>0），模拟值=0.3），表示无干预时背叛的扩散效率。r=0.3，当前 DC=0.2，仅因自然扩散，背叛变化率= 0.3×0.2×0.8=0.048（每周新增 4.8%的背叛者）。

②修复力抑制项“-ζ·PD(t)·DC(t) -ι·HV(t)·DC(t)”是对抗背叛扩散的正向干预，通过两个子项量化“惩罚背叛 PD(t)”和“帮助弱势 HV(t)”对背叛的直接遏制作用，均为负值（抑制增长），且与当前背叛水平 DC(t)成正比（背叛越严重，修复力的作用越关键）。其中：

“-ζ·PD(t)·DC(t)”是对惩罚背叛的抑制，体现“负向激励”对背叛的直接威慑，惩罚越严厉，抑制效果越强。PD(t)是惩罚背叛强度，如对私吞猎物者的驱逐比例、减少分配的幅度，PD=0.8 表示 80%的背叛行为会受到惩罚（如偷猎者被没收猎物）。“ζ”惩罚效率系数 ζ>0，模拟值=0.8，衡量惩罚对背叛的抑制力度。ζ=0.8 时，当 PD=0.7，惩罚的抑制效果= 0.8×0.7×0.3=0.168（每周减少 16.8% 的背叛扩散）。

“$-\iota \cdot HV(t) \cdot DC(t)$”通过改善弱势成员的生存条件，减少因资源匮乏导致的背叛（如老弱无需偷猎），从根源缓解背叛动机。HV(t)是帮助弱势强度（[0,1]），如向老弱分配食物的比例、协助弱势参与狩猎的频次，如 HV=0.6 时表示 60%的弱势成员能获得稳定的食物支持。“ι”是帮助效率系数（$\iota>0$，模拟值=0.5），衡量帮助对背叛的缓解力度，如ι=0.5 当 HV=0.6、DC=0.3 时，帮助的抑制效果 = 0.5×0.6×0.3=0.09（每周减少 9% 的背叛扩散）。

③破坏力驱动项“ $+\sigma_1 \cdot IU(t) \cdot DC(t)+\sigma_2 \cdot |S(t)-F(t)| \cdot DC(t)$”是加速背叛扩散的负向催化，通过两个子项量化 “强加不公”和 “自利-公平失衡”对背叛的刺激作用，均为正值（加速增长），且与当前背叛水平 DC(t)成正比（背叛越严重，破坏力的放大效应越强）。其中：

“ $+\sigma_1 \cdot IU(t) \cdot DC(t)$ ”表示受到强加不公的驱动，体现人为制造的不公平对背叛的直接刺激，当分配明显不公（如首领独占资源），成员更可能通过背叛（如私吞、偷懒）弥补损失。IU(t)是强加不公平的强度，如首领强制占有猎物的比例、分配向亲信的倾斜幅度，IU=0.7 表示 70% 的优质资源被不公分配（如首领独占 70% 的猎物）；“σ_1”是不公敏感系数（$\sigma_1>0$，模拟值 = 0.6)，衡量不公对背叛的催化力度；σ_1=0.6 意味着当 IU=0.7、DC=0.3 时，不公的驱动效果=0.6×0.7×0.3=0.126，即每周增加 12.6%的背叛扩散。

“$+\sigma_2 \cdot |S(t)-F(t)| \cdot DC(t)$”表示自利与公平失衡的驱动，体现自利诉求与公平感知的差距对背叛的放大作用，无论自利过强（S>F）还是公平过强（F>S），都可能打破人们对互惠的预期，自利与公平的动态平衡是合作的基础，失衡都会破坏合作共识，刺激背叛行为。 σ_2 是自利与公平关系失衡的敏感系数（$\sigma_2>0$，模拟值=0.6）；|S(t)-F(t)|是失衡绝对值[0,1]，量化核心自变量自利与公平之间的张力程度（值越高，失衡越严重）。当 S=0.8、F=0.2，失衡绝对值=0.6，表示自利远强于公平，成员更倾向“多占少分”。

背叛传染的瞬时变化率“dDC(t)/dt”的最终值由上述五项共同决定，直接反映修复力与破坏力之间实时博弈的趋势：

当修复力＞破坏力（如惩罚严厉、帮助到位和不公轻微），dDC(t)/dt< 0，背叛比例下降，社会趋向稳定，例如某部落当前 DC=0.3，r=0.3，PD=0.7，HV=0.6，IU=0.5，|S-F|=0.4，代入上述背叛及其传染 DC(t)的微分方程：dDC(t)/dt=0.3×0.3×0.7-0.8×0.7×0.3-0.5×0.6×0.3+0.6×0.5×0.3+0.6×0.4×0.3=0.063-0.168-0.09+0.09+0.072=-0.033，最终为负值，背叛比例下降，社会趋向稳定。

当破坏力＞修复力（如惩罚缺失、帮助不足和严重不公），dDC(t)/dt＞0，背叛比例上升，社会趋向失衡；

阈值临界点是当 DC(t)=0.6（假设 60%成员背叛），超过临界点，即使修复力具有微弱优势，也可能因指数项“（e^(λ(t)·DC (t))）”的放大效应，导致“dDC(t)/dt”的瞬时变化率骤升而触发崩溃风险。

（2）弹性调节指数项“e^(λ(t)·DC (t))”中 的核心意义是通过弹性机制（E）调节λ(t)，进而控制破坏力的增长速度，即弹性越强，λ(t)越小，指数项增长越平缓，对分母的放大作用越弱（即缓冲破坏力）。其中“e”为自然常数，日常计算常用 2.72,“(λ(t)·DC (t))”是指数函数的指数项（幂次）。

弹性调节参数 $\lambda(t)=\lambda_0 /[1+E\_IC(t) \cdot E\_CE(t) \cdot E\_CS(t)]$

“λ0”是初始阈值系数（模拟值=2），代表无弹性时的破坏力增长系数，当 E_IC=E_CE=E_CS=0（整体弹性失效）时，$\lambda(t)=\lambda_0$ =2，此时破坏力指数项增长最快；

常数“1”与上述分母中的作用相同，以下不再重述；

“EIC· ECE· ECS”是 3 个弹性子变量的乘积，体现“个体贡献、集体效率、合作策略”的协同缓冲效应，意味着弹性越强（乘积越大），λ(t)越小，指数项增长越慢，如弹性乘积=1 时，λ=1；弹性乘积=3 时，λ=0.5。

弹性三个子变量（E_IC(t)、E_CE(t)、E_CS(t)）均通过“基础值（常数 1）+ 增益项后，再与两个抑制项（乘积）叠加”构建，体现弹性既受正向因素增强，也受破坏力抑制的特性。弹性三个子变量的微分方程如下：

①个体贡献弹性：

$E\_IC(t)=[1+\alpha \cdot (IC(t)/(1+IC(t)))]\cdot(1-\mu_1 \cdot IU(t))\cdot(1-\mu_2 \cdot DC(t)))$

增益项[α·(IC(t)/(1+IC(t)))]中,IC(t)代表个体贡献强度[0,1]，如个体狩猎次数占比；调节参数α=0.8，表示贡献对弹性的增益系数；IC 趋向 1 时，E_IC 趋向 1+α/2（如α=0.8 时上限为 1.4），容忍度存在上限。抑制项中，μ1 是 E_IC 对 IU 的抑制系数，μ2 是 E_IC 对 DC 的抑制系数；约束范围：μ1，μ2∈(0,1)，μ1 模拟值=0.4，μ2 模拟值=0.3；确保抑制后仍为正，以下同理。

该公式的逻辑体现对不公平的容忍弹性（E），个人贡献越受尊重，越能容忍小范围不公（如接受“多劳多得”），但背叛会削弱这种容忍。

②集体效率弹性：

$E\_CE(t)=[1+\beta \cdot (CE(t)/(1+CE(t)))]\cdot(1-\nu_1 \cdot IU(t))\cdot(1-\nu_2 \cdot DC(t)))$

增益项[β·(CE(t)/(1+CE (t)))]中,CE(t)代表集体效率的正当性[0,1]，如御兽、防御的必要性；调节参数β=1，表示效率对弹性的增益系数；CE 从 0 趋向 1 时，E_CE 从 1 趋向 1+β/2,让渡意愿存在上限，假设原始平等部落中集体目标完全正当（CE(t)≈1），个体最多愿让渡 50%私权（最后通牒实验中最常见的分配提议是五五分成，通常平均占总额的 30-40%（30）),接近上限 1+β/2=1.5。抑制项中，ν1 是 E_CE 对 IU 的抑制系数，ν2 是 E_CE 对 DC 的抑制系数；约束范围：ν1, ν2∈(0,1)，ν1 模拟值=0.3；ν2 模拟值=0.4

该公式的逻辑体现对权利让渡程度的容忍弹性（E），集体目标越正当，越愿让渡私权（如为御兽集中分配食物），但背叛会瓦解集体共识。

③合作策略弹性：

$E\_CS(t)=[1+\theta \cdot (CS(t)/(1+CS(t)))]\cdot(1-\xi_1 \cdot IU(t))\cdot(1-\xi_2 \cdot DC(t)))$

增益项[θ·(CS(t)/(1+CS(t)))]中,CS(t)代表正向合作策略强度[0,1]，如“适度慷慨”的成员比例；调节参数θ=0.7，表示策略对弹性的增益系数；抑制项中，ξ1 是 E_CS 对 IU 的抑制系数，ξ2 是 E_CS 对 DC 的抑制系数；约束范围：ξ1, ξ2∈(0,1)，ξ1 模拟值=0.2，ξ2 模拟值=0.2

该公式的逻辑体现策略对不公平或背叛的缓冲弹性（E），合作策略越普及，越容易维持社会互动，但强加不公会直接破坏策略有效性。

四、环境干扰项 （Environmental Disturbance，Env）

$Env(t)=[1/(1+\omega\_epi\times EPI(t))]\times[1/(1+\omega\_ext\times Ext\_P(t))]$

该公式意在量化自然压力（EPI）和外部冲突（Ext_P）的综合干扰与适配能力，Env (t)越接近 1，外部压力越弱、社会适配能力越强；Env(t)越接近 0，外部压力干扰越强。其中：

第一部分“[1/(1+ω_epi×EPI (t))]”是自然类外部压力项，量化某时刻(t)如地震、干旱、猎物短缺等自然压力的干扰和适配能力，该项的值越接近 1，表示自然压力越小，适配能力越强；该项的值越接近 0，自然压力越大，表示适配能力越弱。分子“1”代表无任何外部压力时的理想环境状态；分母“1+ω_epi×EPI(t)”意在通过线性增长放大压力对分母的影响，确保压力与衰减因子呈反向关联，即自然压力越大，分母数值越大，衰减因子越小。分母的常数“1”与分子的一样也是基础值，同时确保分母不为 0；

第二部分“[1/(1+ω_ext×Ext_P(t))]”是社会类外部压力项，量化某时刻(t)如外部冲突等压力的干扰和适配能力，该项的值越接近 1，表示外部社会压力越小，适配能力越强；该项的值越接近 0，外部社会压力越大，表示适配能力越弱。分子“1”代表无任何外部压力时的理想环境状态；分母“(1+ω_ext×Ext_P(t)”意在通过线性增长放大压力对分母的

影响，确保压力与衰减因子呈反向关联，即社会外部压力越大，分母数值越大，衰减因子越小。分母的常数“1”与分子的一样也是基础值，同时确保分母不为0。
各变量、参数的定义和取值：

参数符号	定义	取值/模拟	核心作用（区分自然社会压力）
ω_epi	自然压力权重系数	ω_epi ＞0 模拟值1.2	放大/缩小自然压力（如灾害）的干扰程度
EPI(t)	自然压力强度（如灾害等级）	[0,1]	0=无自然压力，1=极端自然压力（如特大地震）
ω_ext	外部社会压力权重系数	ω_ext>0 模拟值0.8	放大/缩小社会压力（如外部冲突）的干扰程度
Ext_P(t)	外部社会压力强度（如冲突等级）	[0,1]	0=无外部社会压力，1=极端外部社会压力（如全面战争）

五、动态变化项：κ·γ(t)

该参数的核心功能是从两个方面修正动态平衡度（B (t)），即一边通过κ校准各模块的量级差异，避免 B(t) 过小或过大；一边通过 γ(t) 捕捉部落互动的周期性波动，如季节、协作周期，让模型更贴近“非静态”的现实合作。

κ是基础校准系数（κ>0，模拟值=1.2），核心作用是平衡各模块的数值量级，协调核心平衡项（SF_bal）、张力调节项（T_ten）、环境干扰项（Env）的数值范围，确保B(t)落在[0,1]区间内，便于直观解读“平衡程度”，比如：

SF_bal通常≈0.5（S 与 F 难以完全平衡）、T_ten≈0.3（修复力常弱于破坏力）、Env(t)≥0.4（极端环境下的最低值），三者直接乘积≈0.5×0.3×0.4=0.06，数值过小，难以体现动态平衡度(B(t))的差异。通过κ校准，如κ=1.2，校准后乘积≈0.06×1.2=0.72，虽仍偏低，但差异感更为明显。

γ(t)是动态波动因子，通过正弦函数sin(x)（值域[-1,1]）模拟部落合作的周期性波动，如季节导致的资源变化、惩罚效果的延迟。

γ(t)=1+δ·sin（ωt+φ），其中：

常数“1”代表社会合作关系波动的基准值，对应部落无波动时的合作稳定水平，确保波动不偏离基础平衡。

δ是波动幅度，取值∈(0,0.3)，模拟值=0.2；它的值越大，周期内平衡度的起伏越明显，如冬季δ=0.2，波动强；夏季δ=0.1，波动弱。

ω是角频率，ω=2π/T，π为圆周率，日常计算常用3.14；T为波动周期，它对应波动的时间尺度，短周期T=12，ω≈0.523，如月度协作；长期周期T=365，ω≈0.017，如年度环境。

φ是相位偏移量，取值∈[0,2π)，模拟值=π/2；它体现波动的时间延迟，如惩罚背叛的效果需3个月显现，延迟t=φ/ω，φ=π/2，则对应延迟1/4周期。

提示：基础模型是理论性的，适用于类似旧石器部落的微型社区或权力自利的程度趋向0的社会，实际应用时需要根据具体情境加以完善，包括对变量和参数的增减，以及对变量和参数取值范围的调整。本模型仅作“抛砖引玉”之用，望大方之家不吝赐教。（若商业应

用请联系作者）