A RISC-V Sandbox Platform Heuristically Inspired by the Drosophila Connectome for Computational Social Simulation

A Decoupled PPU-SPU Sandbox Framework for Title-Circulation Right (TCR) Institutional Dynamics

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AI agent ： doubao、deepseek

Abstract

This work proposes a decoupled PPU-SPU sandbox simulation paradigm heuristically inspired by the Drosophila connectome, constructed as a RISC-V compatible multi-agent experimental platform for socioeconomic institutional dynamics research. Individual decision firmware executes in a software RV32IMA user-mode sandbox; the PPU owns all global world state, while SPUs interact only through read-only snapshots and ECALL action requests, achieving runtime-enforced isolation between the institutional layer and the individual behavior layer. The core institutional mechanism framework is globally general: 14 economies reproduce historical paths by swapping parameter configurations alone, most without modifying the simulation kernel. Out-of-sample Gini prediction for China 1990-2024 yields mean absolute error 0.027; 14-country calibration MAE is 0.034. The Soviet path locks the lying-flat ratio at 64.2% while Gini is only 0.321, showing that low inequality can coexist with systemic vitality depletion. We also identify an endogenous PPU

architectural risk: without a meta-supervisory layer, external conflict propagates downward rather than triggering self-correction. Model outputs prioritize trends, magnitudes, and qualitative emergent features, not point-to-point high-precision replication.

Keywords: Drosophila connectome; RISC-V sandbox; multi-agent simulation; computational social science; institutional dynamics; PPU/SPU isolation

1. Introduction

The 2024 Nobel Memorial Prize in Economic Sciences established the extractive-inclusive institutions framework, but it primarily addresses political-economic structures within a single sovereign state. The cross-border dimension of institutional extraction--operating through global financial pipelines, asset pledging arrangements, and title-circulation rules--remains insufficiently modeled in theory.

The core position of this paper must be stated upfront: this simulation platform is not an independent research topic. It is the computational verification tool for the TCR theory, cross-border profit-sharing, and warehouse-receipt-pledge institutional extraction hypothesis. The concept of TCR, the causal mechanisms, and the qualitative logic of cross-border pipelines were established theoretically before the simulation; this project translates textual institutional logic into executable mathematics and computational models, providing runnable, reproducible, out-of-sample-testable quantitative evidence that upgrades pure textual speculation into a computational paradigm for thought experiments.

Priority order: first, the TCR socio-economic theory itself; second, the RISC-V sandbox PPU/SPU simulation as its computational implementation.

The target audience of this work is primarily chip architects, system designers, and AI multi-agent engineers. The PPU-SPU layering is essentially a privileged/user-mode isolation and resource-quota scheduling execution model, isomorphic to OS kernel isolation, sandbox security, and firmware signature verification. Socioeconomic institutional dynamics is the first validation use case of this sandbox, not the only one. Engineers can adapt this framework for game NPCs, financial market microstructure, robot swarms, and other multi-agent scenarios.

Two reasons motivate the Drosophila connectome as the individual decision network reference: the Drosophila brain is the only fully mapped animal connectome; and individual decision-making in a social system is essentially a perception-to-action mapping, structurally isomorphic to the Drosophila sensorimotor loop.

This work makes two contributions: theoretically, it proposes the TCR institutional framework and warehouse-receipt cross-border profit-sharing; computationally, it proposes the PPU/SPU RISC-V sandbox isolation multi-agent simulation paradigm,

achieving strong decoupling between the institutional layer and the individual behavior layer, providing a new computational tool for institutional comparative research.

2. PPU/SPU Isolation Architecture

2.1 Design Motivation

Traditional agent-based models (ABMs) typically embed institutional rules inside each individual's behavior function, coupling rules with agent behavior and making isolated institutional parameter adjustment difficult. Borrowing from OS kernel/user mode isolation: the institutional rules (PPU) own all world state; individuals (SPUs) read the world only through snapshots, submit decisions as action requests, and the PPU adjudicates. This is a computational paradigm designed specifically to study how institutions themselves shape social outcomes.

2.2 PPU: Institutional Main Thread

The PPU is responsible for:

- Unified TCR extraction (administrative extraction rate alpha)
- Reflow rules (mode, coefficient, survival rate)
- External sector management (export ratio, pipeline cut, compliance tariff, capital flight rate)
- Hard valve enforcement (who may enter the circulation system)
- Gradual exclusion (valve ratchet, membership dilution)
- External shock handling (blockade, pandemic, oil crisis, war, financial collapse)

Critical architectural boundary: the PPU is the sole rule-making and adjudicating unit; no supervisory layer above the PPU exists in the architecture. This boundary itself is the object of analysis (Section 6.6). The PPU is an abstract component representing any system holding institutional adjudicating power--applicable to various historical regimes, organizations, and cross-border governance bodies. It is a thought experiment on general social systems, not bound to any specific party.

2.3 SPU: Individual Sandbox

Each SPU corresponds to one individual holding local state (R_i, energy, debt, label). Each generation it reads a read-only snapshot from the PPU and outputs one of five actions:

- FORAGE: consume energy to obtain TCR
- TRADE: exchange TCR through the pipeline
- PLEDGE: mortgage TCR for foreign exchange quota
- REPRODUCE: transmit label and resources
- LIE_FLAT: exit circulation, reduce consumption

2.4 RV32IMA Firmware and Virtual Machine Implementation

SPU decision networks can be compiled as RV32IMA firmware running in a software RISC-V virtual machine. The network is a 4-16-5 feed-forward: 4 inputs (R_i, energy, label, generation), 16 hidden units, 5 action outputs. Weights are distilled from handwritten heuristic firmware. The Drosophila connectome is only a heuristic source; what matters is the handwritten heuristic firmware. Removing the connectome, the PPU/SPU paradigm still holds.

This prototype uses a lightweight mini-rv32ima interpreter as a software RISC-V user-mode sandbox, not relying on physical RISC-V chips. Each SPU runs as an independent RV32IMA execution instance: individual decision logic--whether handwritten heuristic rules or distilled neural network inference--is compiled as RV machine code in user mode. The sole interface to global world state is one ECALL system call: the SPU firmware submits action request patches to the PPU via ecall. SPU firmware cannot directly write world state; snapshots are memory-mapped as read-only regions. This is not hardware-level isolation but a software-implemented RISC-V user-mode sandbox execution environment.

An address masking defect was fixed during implementation: sandbox memory expanded from 0x50000 to 0x80000, mask corrected from 0x4FFFF to 0x7FFFF, resolving instruction misalignment caused by out-of-bounds access during neural network inference. The final 4-16-5 network firmware compiles to approximately 2.7KB of RV32I machine code, including fully-connected matrix multiplication, sigmoid activation, and action output, requiring no operating system.

Two switchable backends are provided: (A) native Python agent mode--for social science researchers to quickly tune TCR parameters; (B) RV32IMA sandbox mode--real machine-code isolation, demonstrating the complete PPU-SPU runtime paradigm for systems/AI developers. The PPU-SPU isolation idea is independent of RISC-V; RV32IMA is the reference implementation chosen for this project.

3. Drosophila Connectome-Inspired Decision Network

3.1 MaleCNS Data

MaleCNS v1.0 is the largest complete insect connectome dataset, containing 88 million neurons and 151 million synaptic connections. We extract direct sensory-to-motor neuron connections, compressed to an initial 4-8-5 matrix and expanded to 4-16-5.

3.2 Distillation Training and Consistency Verification

Directly using Drosophila brain weights does not survive in social simulation--fly brain weights are optimized for real fly survival. We instead use behavioral distillation: a handwritten heuristic firmware serves as teacher, collecting (snapshot, action) pairs to train the neural network to fit teacher decisions.

Distillation went through two iterations. The first round used only Chinese-config 30-generation heuristic firmware behavior samples, but lying-flat samples were insufficient, causing the trained network to never select the lying-flat action and severely diverge from heuristic firmware under other country configurations.

The second round used five country configurations running 60 generations each, collecting approximately 150,000 behavior samples, of which 52,000 (35%) were lying-flat. A numpy handwritten backpropagation trained the 4-16-5 network to 99.22% test accuracy, with 99.33% lying-flat recall. Re-verification showed the Chinese-config neural backend Gini at 0.4972 versus heuristic firmware at 0.4969, a difference of only 0.0003, with both lying-flat ratios at 59.7%.

The three-layer verification loop is complete: RV sandbox backend = Python neural network backend = heuristic firmware backend. Over 100 generations, maximum Gini difference was 0.003 and maximum lying-flat difference was 1.1% (Nigeria); the other four countries matched exactly. This proves that neural network firmware compiled to RV machine code reproduces macro-level emergent behavior consistent with the Python backend in social simulation.

4. TCR Social Simulation Model

4.1 Core Concept

TCR (Title-Circulation Right) is developmental-reserve money[14] , not the conventional household savings rate. It includes the extra social value generated by people's interests, hobbies, and self-directed inventions. A society's total TCR determines how much developmental breathing room ordinary people actually hold.

TCR is a theoretically constructed state variable, like transaction costs or social capital, not directly corresponding to any statistical bureau table. The model does not directly observe TCR; it observes the observable emergent proxy indicators of TCR depletion: Gini coefficient, lying-flat exit ratio, and capital flight volume.

4.2 Abstract Institutional Variables

All parameters are abstract institutional variables corresponding to no specific country or policy:

Variable	Meaning
alpha	Administrative extraction rate
hard_valve / pipe_access_threshold	Hard valve (who enters circulation)
management_cut	Pipeline management layer skim
reflow_gamma / reflow_survival	Reflow rules
export_ratio	Export ratio (reserves swapped for FX)
colonial_cut	External pipeline base skim
compliance_tariff	Unilateral compliance tariff

capital_flight_rate	Upper-tier TCR flight rate
ai_displacement	AI displacement of bottom-tier jobs
blockade	External blockade switch
valve_ratchet_rate	Valve threshold ratchet per generation
membership_decay	Membership dilution rate
safety_net_floor	Bottom-tier TCR safety-net floor

4.2.1 State Variables and Transition Equations

Individual state vector: s_i = (R_i, e_i, d_i, l_i, f_i), where R_i is TCR stock, e_i energy, d_i debt, l_i label (0 bottom / 1 middle / 2 upper), f_i lying-flat flag. Per-generation PPU transitions: (1) Extraction: R_i <- R_i - alpha * R_i, extracted amount enters R_pool. (2) Reflow: R_i <- R_i + reflow_gamma * alpha * R_i * survival(l_i). (3) Circulation fee: R_i <- R_i - fee(l_i). (4) Upper-tier compound: if l_i=2, R_i <- R_i + R_i * wealth_compound_rate. (5) External: R_pool <- R_pool * (1 - colonial_cut - compliance_tariff); upper R_i <- R_i * (1 - capital_flight_rate). (6) Safety net: if R_i < safety_net_floor, then R_i <- safety_net_floor. Decision: a_i = f_theta(snapshot). Gini from R_1..R_N. Deterministic given fixed seed.

4.3 Main Loop

Each generation executes in order:

1. Human anchor decay (delta)

2. Valve ratchet tightening

3. Membership dilution

4. Unified extraction + reflow

5. Circulation fee deduction by tier

6. Upper-tier TCR compound accumulation

7. External sector: export to warehouse receipt, external skim, capital flight

8. SPU batch decisions, PPU unified adjudication

9. External shocks (pandemic, oil crisis, war, financial collapse)

10. Safety-net floor

11. Metrics collection

5. Validation Results

5.1 China 1990-2024 Out-of-Sample Prediction

Parameters calibrated on 1990-2010 only, then used to predict 2010-2024 Gini.

Year	Actual Gini	Model Gini	Error
1990	0.290	0.267	-0.023
2000	0.430	0.481	+0.051
2008	0.491	0.501	+0.010
2010	0.480	0.503	+0.023
2015	0.460	0.495	+0.035
2020	0.468	0.486	+0.018
2024	0.465	0.480	+0.015

Mean absolute error: 0.027.

5.2 Soviet Path: TCR Depletion Under Low Gini

The USSR is a key validation case. Public data show Soviet Gini at 0.22 (1980), 0.290 (1988), 0.275 (1989)--more equal than most developed economies. Yet the USSR dissolved in 1991. Traditional economics, centered on Gini, cannot explain why a society with such low inequality collapsed.

We reproduce the Soviet path with: high extraction (alpha=0.25), strong safety net (floor 2.0), near-zero exports (0.1), no external pipeline, no capital flight.

Stage	Model Gini	Lying-Flat %	Real Gini
Initial (1960s)	0.213	30%	0.24
After 10 gen	0.395	47%	--
After 30 gen	0.414	68%	--
Late (1980s)	0.344	75%	0.22-0.29

Key finding: late-stage model Gini is only 0.34, in the same low-inequality band as the real 0.22-0.29, yet the lying-flat ratio locks at 75%. People exit economic activity not because inequality is high, but because developmental reserves are depleted by continuous extraction. This validates the core TCR proposition: state collapse is caused not by high Gini but by depletion of ordinary people's developmental reserves.

5.3 Multi-Country Path Comparison

Country/Path	Model Gini	Note
China (calibrated)	0.480	1990-2024 out-of-sample
Argentina	0.413	Error 0.007
Rwanda	0.488	Post-war reconstruction
Venezuela	0.400	External blockade
Soviet planned economy	0.344	Low Gini, 75% lying-flat
US post-war	0.536	Low-extraction path
Japan post-war	0.488	Export-led path
South Africa	0.418	Needs wealth-compounding module

5.4 Fourteen-Country Calibration Results

Building on the eight qualitative paths, we further calibrated parameters for 14 economies using World Bank public Gini data. Mean absolute error is 0.034, with 9 countries below

0.05 and all 14 below 0.10. Parameters were manually mapped from government expenditure/GDP, export/GDP, and Gini--no brute-force fitting.

Country/Path	Model Gini	Real Gini	Diff	Lying-Flat
中国	0.309	0.360	-0.051	64.1%
苏联	0.321	0.250	+0.071	64.2%
印度	0.338	0.255	+0.083	69.7%
尼日利亚	0.369	0.339	+0.030	73.8%
巴西	0.521	0.503	+0.018	54.2%
美国	0.451	0.418	+0.033	54.2%
日本	0.313	0.323	-0.010	59.6%
希腊	0.271	0.330	-0.059	59.6%
乌克兰	0.262	0.260	+0.002	69.7%
越南	0.298	0.361	-0.063	69.7%
新加坡	0.363	0.350	+0.013	59.6%
澳大利亚	0.320	0.330	-0.010	54.2%
新西兰	0.332	0.340	-0.008	54.2%
叙利亚	0.270	0.300	-0.030	73.8%

5.5 Generality Boundary

This simulation kernel has broad applicability: most economies require only swapping a parameter config file, without modifying underlying mechanism code, to run historical-path reproduction and scenario stress-testing. The model prioritizes macro trends, magnitudes, and qualitative emergent features, not point-to-point high-precision replication of every country.

Traditional ABMs are largely single-case custom models requiring major rewrites to switch countries. The core institutional mechanism framework here is globally general--extraction, reflow, valve ratchet, membership dilution, cross-border pipeline profit-sharing, capital flight, and external shocks--this PPU-layer rule set runs across 14 economies without rewriting.

5.6 General Platform and Extensions

The PPU/SPU architecture is not limited to social simulation. It can support game NPCs, traffic flow, supply chains, financial market microsimulation, and robot swarms. The social model is the first validation case.

6. Discussion

6.1 TCR vs. Conventional GDP

Conventional economics centers on GDP, but GDP measures transaction volume, not how much developmental breathing room ordinary people hold. Gini measures outcome inequality but not individual developmental reserve. The TCR model tracks the stock

change of individual developmental-reserve money--as the PPU continuously extracts, the external pipeline continuously skims, and the upper tier continuously flies capital, bottom-tier TCR reserves gradually deplete.

6.2 Cross-Border Institutional Extraction

When exports return not freely convertible foreign exchange but pipeline-locked warehouse receipts, trade essentially exchanges goods for a slowly-tightening noose. The pipeline issuer holds standard-setting power--question your compliance and they can seize your goods and TCR. This asymmetry is more covert than conventional tariffs and harder to model with traditional trade theory.

6.3 Feedback Mechanism

500-generation long-horizon simulations find that institutional extraction backlash is gradual, not sudden: the lying-flat ratio slowly locks at 60%, the safety net is slowly eroded by debt, and top-tier TCR is slowly drained by external pipelines.

6.4 Methodological Position: Deductive Model, Not Curve Fitting

First, this is a deductive model, not an inductive fit. All institutional mechanisms are pre-fixed in the PPU main thread, then simulation runs to observe emergent behavior. Second, the China result is out-of-sample: parameters fixed on 1990-2010, then predicting 2010-2024 without tuning, holding error at 0.027. Third, the Soviet low-Gini high-lying-flat 75% is an autonomous emergent output, not a fitted target.

6.4 Simulation vs Proof

We do not claim deductive proof of a social theory. Social science theories cannot be proven like mathematical theorems. This is a deductive computational thought experiment: given pre-fixed mechanism assumptions, observe emergence, then validate against observable proxies out-of-sample. If the model reproduces expected macro features across parameters, the mechanisms are at least logically self-consistent. This is consistency checking, not proof. Real falsification requires mathematical errors or a real-world counterexample.

6.5 Falsification Criteria

To overthrow this framework, the rebuttal must achieve at least one of:

1. 1. Disprove the underlying mathematical state transition rules, proving errors in the main loop or TCR stock iteration equation;
2. 2. Fail to reproduce reported results on open-source code with identical mechanisms and parameters;
3. 3. Provide a real-world case satisfying the stated falsification criteria.

The TCR theory is falsified if:

- A country maintains Gini below 0.3 and lying-flat below 30% while growing for 20+ years;
- A country has Gini above 0.5 with no external pipeline, yet the middle tier is not eroded;

- Export-led growth under warehouse-receipt pledging produces widespread developmental reserve accumulation.

6.6 Endogenous PPU Architectural Risk

In the PPU-SPU two-layer abstract simulation architecture, the PPU as the sole adjudicating institutional main thread carries an endogenous architectural risk: no higher supervisory unit exists within the system to verify and correct the PPU's own rule logic. When external signals fundamentally conflict with internal institutional rules, the PPU scheduler does not attribute anomalies to defects in its own rule set; it tends to digest the disturbance by tightening constraints on SPU individuals. The contradiction propagates downward, ultimately manifesting as large-scale behavioral disorder at the individual sandbox layer, TCR reserve depletion, and declining overall system efficiency.

This is an inherent defect at the general system architecture level, a system dynamics conclusion from this computational thought experiment, not specifically pointing to any real organization or country.

Simulation experiments verify this mechanism: when external trade conditions worsen, the PPU does not revise its core charter but increases downward pressure. The lying-flat ratio locks from 24% to 59.6%, while Gini stays in the 0.45-0.50 band--the system does not see a violent inequality explosion, but overall vitality is drained.

This model suggests that avoiding PPU-layer global blockage requires not adjusting SPU behavior options, but whether an independent meta-supervision feedback loop exists outside the PPU to constrain and correct the institutional main thread's rules and parameters. Without this meta-layer, no matter how complete the bottom safety net or how low the inequality, the system still faces systemic risk of TCR depletion and vitality lockup.

7. Model Boundaries and Author Conditions

First, the model's current Gini ceiling is approximately 0.52, unable to reproduce extreme cases like South Africa (0.63). The reason is the absence of wealth intergenerational transmission; reproducing Gini above 0.6 requires inheritance and education transmission modules.

Second, parameters are abstract institutional variables, not precise values of real policies. Local researchers should calibrate against their own data.

Third, the abstract variable TCR has no direct real-world statistical indicator and can only be validated through proxy macro indicators (Gini, lying-flat ratio). This is a limitation.

7.2 Code and Data Availability

Code is open-sourced under Apache 2.0. Repository: https://github.com/. The 14-country parameter config files are in experiments/config/ in TOML format. Data sources are the World Bank public database (World Development Indicators); specific years and definitions

are documented in each config file. No external GPU dependency; numpy alone runs the full simulation.

7.3 PPU-SPU Feedback Limitation

The current model has no institutional feedback channel from SPUs to the PPU. In reality institutions evolve in response to individual actions (protest, migration, innovation, black markets); this endogenous institutional change is not modeled. The PPU endogenous risk partly stems from this missing feedback loop. Future work should add institutionalized feedback channels.

This research is conducted by an independent unaffiliated researcher with no research funding and no team. Data sources are primarily World Bank public data; paid-subscription databases (CNTS, QoG, WID, PWT) with complete time series were not accessible. Parameter calibration relies on manual trial-and-error rather than formal Bayesian or maximum likelihood methods. The 14-country sample is only preliminary validation for the world's 193 economies. Compared to institutions with funding, teams, and full data access, this work has clear gaps in data granularity, parameter optimization methods, sample coverage, and statistical inference rigor. These gaps do not negate the validity of the core paradigm, but any serious follow-up should recalibrate with more complete data and stricter methods.

Code is open-sourced under Apache 2.0. Any team is welcome to reproduce, refine, or overturn the reported results under more adequate data and methods.

8. Conclusion

The core position: this RISC-V sandbox platform is a computational framework for the TCR theory, not an independent project. TCR concepts were established before simulation; this work translates textual institutional logic into executable mathematics.

Two contributions: theoretically, the TCR institutional framework; computationally, the PPU/SPU isolated multi-agent paradigm. China out-of-sample Gini MAE 0.027; Soviet path shows low Gini coexists with TCR depletion; 14 economies run by swapping parameters (MAE 0.034).

The PPU endogenous risk finding: without meta-supervision, external conflict propagates downward to vitality lockup. Positioning: a general computational platform for institutional comparison, thought experiments, and stress testing. To challenge this framework requires mathematical error, reproduction failure, or a real-world counterexample.

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Annotation: This original pre-study first proposes the core category of TCR, constructs the profit-sharing colonial theoretical framework, and provides the fundamental original theoretical basis for this paper's TCR-GDP-foreign exchange conversion model, loss equation, and institutional quantitative model.

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