Theoretical Foundations — Companion Document

Computational Policy Analysis Framework (CPAF v6)

A theory-by-theory guide to the computational mechanisms in the seven-dimensional policy simulation, and to the validation and robustness evidence that supports them.

Based on :

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1. Introduction

This companion provides a systematic, theory-by-theory exposition of every major academic concept computationally operationalised within CPAF v6. Its purpose is fourfold.

First, it demonstrates that every modelling decision in CPAF is grounded in established theory, not arbitrary design. Each mechanism — from the sigmoid diffusion curves to the attractor-basin thresholds — traces to a specific academic source.

Second, it provides examiners, reviewers, and practitioners with a standalone reference mapping abstract theory to concrete computational implementation. For each theory the document explains: what the theory says, how CPAF operationalises it, which dimension(s) it appears in, and what it enables the model to do that single-lens analysis cannot.

Third, it makes the architectural logic explicit. The framework is not seven independent modules; it is an integrated system in which theories from different traditions interact through bidirectional runtime couplings. This document makes those interactions visible.

Fourth, it states honestly what the model is and is not. CPAF is a proof of concept and a structured-reasoning instrument, not an empirically-calibrated forecaster. Sections 12 and 13 present the validation and robustness evidence that justifies confidence in its *conclusions* while disclosing the softness of its *numbers*.

> *Organising principle: theories are presented in the order they appear in the simulation's execution cycle — the cross-cutting complexity layer that governs all dimensions first, then D1–D7 individually, then the couplings, the validation, and the robustness evidence.*

2. Cross-Cutting Complexity Layer

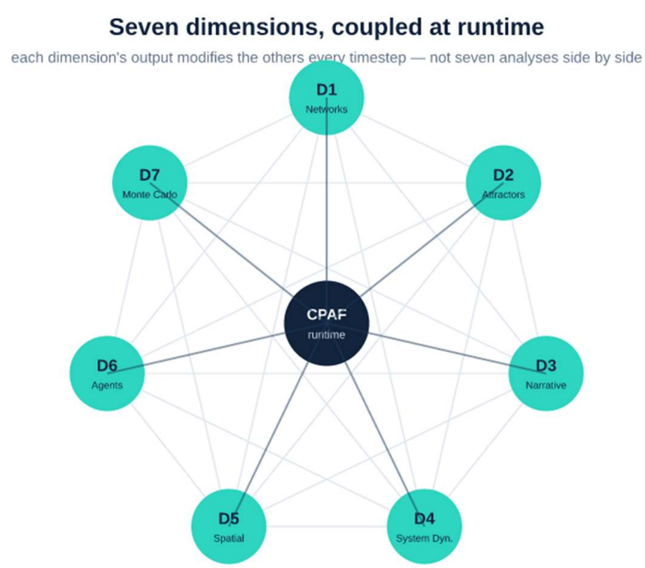

Figure 1: Seven dimensions coupled at runtime — the model architecture.

2.1 Complexity Theory

The theory. Complexity theory (Holland, 1995; Byrne & Callaghan, 2014; Cairney, 2012) holds that social systems are complex adaptive systems: nonlinear, feedback-rich, emergent, self-organising, path-dependent. Unlike merely complicated systems, their behaviour cannot be reduced to the sum of parts; small interventions can produce large effects and large interventions none at all, depending on the system's state.

CPAF operationalisation. Complexity is not a module; it is a property of the architecture. The seven dimensions are not computed independently and summed — they interact through bidirectional couplings at every timestep, so coordination affects the regime, which affects political feasibility, which feeds back to coordination. That circular causality is what makes the system complex adaptive rather than additive.

> **Dimensions:** all (D1–D7). **Mechanism:** bidirectional runtime couplings across a layered complexity system. **Property captured:** emergence — system-level outcomes (poverty-trap persistence, portfolio redundancy) arise from dimension interactions, not any single dimension. **References:** Holland (1995); Byrne & Callaghan (2014); Cairney (2012). *Model insight: with complexity enabled, escape from the trap takes longer and succeeds less often than a linear model predicts — the property working as designed, later confirmed by the validation suite.*

2.2 Punctuated Equilibrium Theory (PET)

The theory. PET (Baumgartner & Jones, 1993, 2009; drawing on Eldredge & Gould, 1972) argues that policy systems show long stability punctuated by sudden shifts. Negative feedback — inertia, bounded rationality, issue monopolies — maintains equilibrium; punctuation occurs when accumulated pressure overwhelms those mechanisms.

CPAF operationalisation. PET governs the between-regime transitions. The model defines three attractor states — **TRAP, TRANSITION, and GROWTH** — separated by thresholds. Within a regime the system resists change; a transition occurs only when cumulative policy pressure, amplified by coordination (D1) and narrative alignment (D3), carries income across the basin boundary *and holds it there long enough to confirm* (hysteresis; see §4.2). The result is the PET signature: long flat stretches where income barely moves despite active policy, followed by a comparatively sharp regime change.

> **Dimensions:** D2, with inputs from D1 and D3. **Mechanism:** threshold- and duration-gated transitions between attractor basins. **Property captured:** discontinuous change. **References:** Baumgartner & Jones (1993); True et al. (2007). *Visual metaphor: a ball in a bowl (TRAP). Policy tilts the landscape; the ball rolls back until the tilt is sustained past a critical angle, then drops into the GROWTH bowl. The depth of the TRAP bowl is why escape needs sustained, coordinated pressure — not a one-off push.*

2.3 Panarchy and the Adaptive Cycle

The theory. Holling's (1973, 2001) adaptive cycle moves systems through exploitation, conservation, release, and reorganisation; Panarchy (Gunderson & Holling, 2002; Walker et al., 2004) nests these cycles across scales, with "revolt" and "remember" transmitting disruption and memory between levels.

CPAF operationalisation. CPAF captures multi-scale dynamics through the interaction of fast-cycling agent decisions (D6, each timestep) and slow-cycling regime shifts (D2, over many timesteps). The heritage–skills coupling embodies "remember": accumulated craft knowledge stored in the skills stock is slow-variable memory that constrains the speed of income recovery. When skills erode below a critical level, the system loses that memory and cannot reorganise.

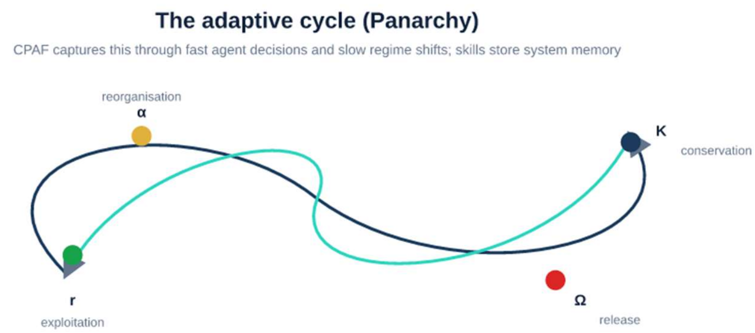

Figure 2: The adaptive cycle — exploitation, conservation, release, reorganisation, nested across scales.

> **Dimensions:** D2, D4, D6 (multi-scale). **Mechanism:** heritage–skills coupling; fast/slow variable interaction. **Property captured:** cross-scale dynamics and system memory. **References:** Holling (1973, 2001); Gunderson & Holling (2002); Walker et al. (2004).

2.4 Logistic Growth and S-Curve Dynamics

The theory. The logistic model, $dN/dt = rN(1-N/K)$, describes processes that start slowly, accelerate, and saturate at a carrying capacity. In policy diffusion (Rogers, 2003), adoption follows an S-curve: few early adopters, then rapid uptake past a critical mass, then saturation.

CPAF operationalisation. CPAF applies sigmoid functions to within-regime policy diffusion: an activated policy's reach follows an S-curve modulated by spatial context (D5) — urban segments saturate faster (×1.0) than peri-urban (×0.7) or rural (×0.4), producing realistic adoption lags and explaining why the same scheme reaches full diffusion in urban Lucknow but stalls in rural Telangana.

Critical distinction from PET. The S-curve governs *smooth, continuous* change within a regime; PET governs the *discontinuous jump* between regimes.

Figure 3: Two kinds of change — the S-curve within a regime versus the punctuated jump between regimes.

> **Dimensions:** D4, D5, D7. **Mechanism:** sigmoid reach functions with spatial modifiers. **Property captured:** within-regime nonlinearity — diminishing returns and saturation. **References:** Rogers (2003); Mahajan & Peterson (1985).

2.5 Poverty Trap Theory

The theory. Poverty-trap theory (Azariadis & Stachurski, 2005; Barrett & Carter, 2013; Banerjee & Duflo, 2011) formalises poverty as a *stable equilibrium*: self-reinforcing mechanisms (low income → low investment → low productivity → low income) create a basin that resists escape. Structural traps, unlike transient poverty, require a critical threshold of simultaneous interventions to shift basins.

CPAF operationalisation. The TRAP attractor implements this directly, now on documented lines. Income is a level: **income = subsistence + headroom × quality(skills, market) × share(1 − middlemen)**. The floor is the **destitution line, ₹1,450** (World Bank $2.15/day, 2017 PPP); the **poverty line / TRAP threshold is ₹2,000** ($3.00/day, 2021 PPP); the **viability / GROWTH threshold is ₹4,122** (rural MPCE, India HCES 2023-24). Below the poverty line, self-reinforcing loops — middleman capture, youth exit, skill erosion, credit lock-in — hold the low equilibrium; above the viability line, virtuous cycles sustain momentum; between them lies the unstable TRANSITION zone.

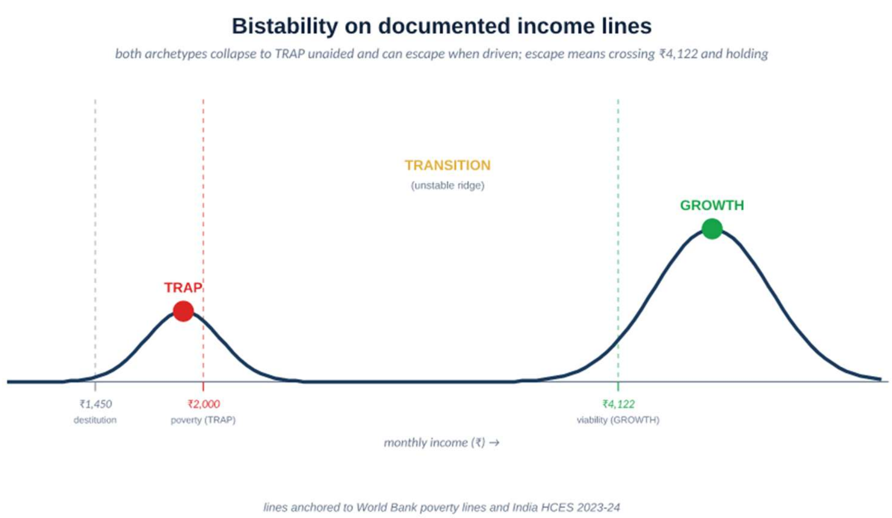

Figure 4: Bistability on documented income lines — TRAP and GROWTH as two attractors.

Both case archetypes are bistable — left unaided each collapses into the trap, and each can escape when driven. Their difference is not that one is trapped and one is not, but *which lever* releases them (see §13.2). The validation suite confirms the trap is a genuine attractor, not a statistical artefact.

> **Dimensions:** D2, D4. **Mechanism:** self-reinforcing loops maintaining a low-income equilibrium below the anchored poverty line. **Property captured:** multiple equilibria with asymmetric stability. **References:** Azariadis & Stachurski (2005); Barrett & Carter (2013); Banerjee & Duflo (2011).

3. D1 — Graph Theory, Networks, and the Two Coordination Streams

Dimension 1 models coordination as a network property. Crucially, coordination is **two distinct streams**, not one.

- The **artisan co-op ($C \in [0,1]$)** is a *producer-side* network. Built by cluster investment once it crosses a critical-mass threshold, it supplies the bargaining power that — combined with a market channel — breaks the middleman monopsony. It is a lever, not a multiplier.

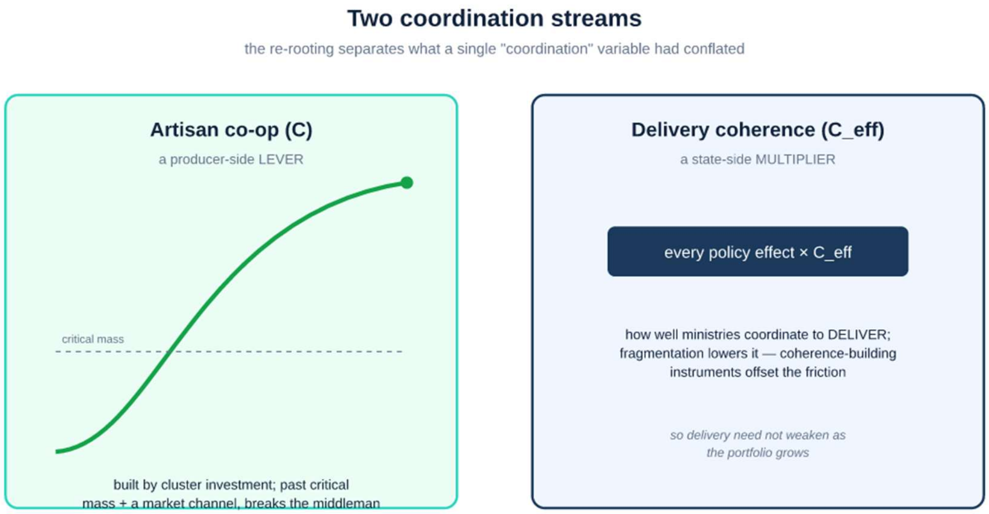

Figure 5: The two coordination streams — the co-op (a lever) versus delivery coherence C_eff (a multiplier).

- **Inter-ministry delivery coherence (C_eff)** is a *state-side* network property: how well ministries coordinate to *deliver*. It is the multiplier that scales the effect of every policy. Portfolio fragmentation lowers it; coherence-building instruments offset that friction, so delivery does not automatically weaken as a portfolio grows.

Keeping these apart lets the model show that fragmentation friction is real but bounded (validation result R6): more policies do not automatically weaken coordination, because coherence-building instruments offset the friction.

3.1 Strength of Weak Ties (Granovetter)

The theory. Granovetter (1973, 1983) showed that weak ties — acquaintance-level bridges between clusters — carry information across a system better than strong within-group ties. In policy networks, the critical link is often the weak cross-ministry tie (Textiles ↔ MSME ↔ Commerce), not dense within-ministry coordination.

CPAF operationalisation. Delivery coherence C_eff aggregates cross-ministry network density. Low C_eff means siloed ministries — policies needing multi-ministry inputs (an SFURTI cluster needing both MSME infrastructure and Textiles training) cannot be fully delivered. On the producer side, weak market-linkage ties are exactly what the connective-failure archetype lacks and what a market-access lever restores.

> **References:** Granovetter (1973, 1983); Borgatti & Halgin (2011).

3.2 Policy Network Theory

The theory. Policy network theory (Rhodes, 1997; Kenis & Schneider, 1991; Marsh & Rhodes, 1992) treats policymaking as occurring within networks of interdependent actors; structure — who is connected, who controls resources, who has information — shapes feasibility and delivery. Betweenness centrality identifies gatekeepers.

CPAF operationalisation. CPAF models five ministries (Textiles, MSME, Minority Affairs, Commerce, Culture) as nodes whose connectivity is read as C_eff. In the value chain, the middleman's high betweenness — nearly all economic flows pass through intermediaries — explains why training-only interventions fail: skills rise but the income gains are captured by the high-betweenness intermediary unless the co-op and a market channel route around it.

> **References:** Rhodes (1997); Kenis & Schneider (1991); Marsh & Rhodes (1992).

3.3 Advocacy Coalition Framework (Sabatier)

The theory. Sabatier's (1988; Sabatier & Jenkins-Smith, 1993) ACF posits competing coalitions united by belief systems; change comes through shocks, learning, or negotiation, and coalition stability explains inertia.

CPAF operationalisation. CPAF models a welfare-oriented and a market-oriented coalition, whose relative strength is the political feasibility state $P \in [0,1]$. When $P < 0.30$ the welfare coalition dominates and market policies are blocked; when $P > 0.70$ the reverse. Coalition strength shifts with outcomes — successful welfare policy strengthens the welfare coalition — producing the path dependence ACF predicts.

> **Dimensions:** D1 ↔ D3. **References:** Sabatier (1988); Sabatier & Jenkins-Smith (1993); Weible et al. (2011).

4. D2 — Attractor Analysis

4.1 Nonlinear Dynamics and Attractors (Strogatz)

The theory. In dynamical-systems theory (Strogatz, 2015), an attractor is a state a system evolves toward from a range of initial conditions; its basin is the set of those conditions. Perturbations smaller than a basin's depth are absorbed; larger ones trigger transitions.

CPAF operationalisation. CPAF defines three states with asymmetric stability: **TRAP** (deep, high stability), **TRANSITION** (shallow, unstable), and **GROWTH** (a desired but weakly self-holding target). The asymmetry is deliberate: the TRAP state applies a 0.95 income drag, while the GROWTH state earns no auto-reinforcement bonus, so it must be sustained by continuing policy support rather than coasting. This formalises the empirical observation that dysfunctional equilibria in craft clusters are more stable than functional ones.

> **References:** Strogatz (2015); Scheffer (2009); Meadows (2008).

4.2 Critical Transitions and Regime Shifts (Scheffer)

The theory. Scheffer (2009; Scheffer et al., 2012; Dakos et al., 2012) showed that regime shifts are preceded by early-warning signals — critical slowing, rising variance, flickering — and are often hysteretic: the conditions to trigger a forward shift differ from those to reverse it.

CPAF operationalisation. CPAF implements this as duration-gated hysteresis. To confirm escape into GROWTH, income must hold above the growth line for a sustained window (operationally, on the order of eighteen months of the model's clock), not merely cross it once. Falling back requires income to drop meaningfully below the line and stay there. A cluster that has escaped therefore needs less support to remain in GROWTH than to escape initially — but if support is withdrawn prematurely and it falls, re-escape demands the full original effort. The TRANSITION state is the "flickering" zone Scheffer identifies as a precursor to a shift.

> **Property:** hysteresis and early-warning behaviour in transitions. **References:** Scheffer (2009); Scheffer et al. (2012); Dakos et al. (2012).

5. D3 — Narrative Policy Framework

5.1 NPF Core Framework (Jones, McBeth, Shanahan)

The theory. The NPF (Jones & McBeth, 2010; Shanahan et al., 2018, 2023) treats policy narratives as measurable objects with setting, characters (hero/villain/victim), plot, and moral, operating at micro, meso, and macro levels.

CPAF operationalisation. CPAF implements NPF at the meso level through the political feasibility state P and its narrative dynamics. Each regime generates a characteristic narrative: in TRAP, middlemen or market forces are the villain and welfare the hero; in GROWTH, bureaucratic interference becomes the villain and market innovation the hero. This is not decorative — narrative alignment (active policy type matching the dominant narrative) boosts effectiveness, misalignment reduces it, and successful policies shift narratives, producing narrative lock-in: a path dependence standard models miss.

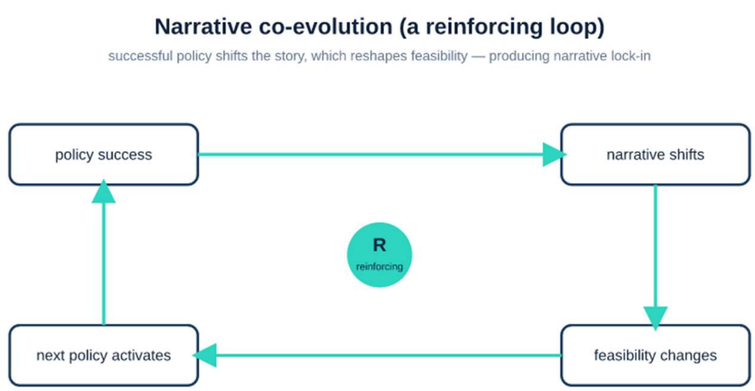

Figure 6: Narrative co-evolution — a reinforcing loop producing narrative lock-in.

> **Property:** narrative–policy co-evolution creating path dependence. **References:** Jones & McBeth (2010); Shanahan et al. (2018, 2023).

5.2 Political Feasibility and Coalition Friction

The theory. Political-feasibility analysis (May, 1986; Meltsner, 1972; Kingdon, 1984) asks whether a technically sound policy can actually be adopted, given actor support, veto points, and framing.

CPAF operationalisation. CPAF implements feasibility as a gate: policies outside the window defined by P are blocked regardless of technical merit. At P = 0.50 both stances are feasible with no boost; below 0.30 market policies are blocked; above 0.70 welfare policies face resistance. Narrative inertia makes P shift slowly, so environments change only gradually.

> **References:** May (1986); Meltsner (1972); Kingdon (1984).

6. D4 — System Dynamics

6.1 System Dynamics Methodology (Forrester, Sterman)

The theory. System dynamics (Forrester, 1961; Sterman, 2000) models systems with stocks, flows, and feedback loops; reinforcing loops amplify, balancing loops resist, and structure — not events — determines behaviour over time.

CPAF operationalisation. D4 is the computational core. The engine tracks the primary stocks (artisan population, income, skills, market access, the co-op, heritage, middleman power) through flow equations each timestep. Central loops include:

- **R1 (skill–income virtuous cycle):** income → training → skills → productivity → income; dormant at low income, activating above the TRANSITION threshold.
- **R2 (market-access cycle):** market access → revenue → investment → market access; requires both skills and a delivery-coherent portfolio.
- **R-CREDIT (the trap loop, reinforcing):** low income → credit dependence → middleman lock-in → extraction → low income. A reinforcing loop: it *deepens* the trap rather than stabilising it.
- **B-FRAG (fragmentation friction, balancing):** a growing portfolio raises inter-ministry friction, lowering delivery coherence C_eff — offset, not always overwhelmed, by coherence-building instruments.

> **References:** Forrester (1961); Sterman (2000); Meadows (2008).

6.2 Leverage Points (Meadows)

The theory. Meadows (1999, 2008) ranked twelve leverage points: parameter tweaks are weakest; feedback structure, rules, goals, and paradigms are progressively stronger.

CPAF operationalisation. CPAF demonstrates the hierarchy empirically. Parameter-level interventions (raising one policy's funding 20%) barely move the TRAP attractor; structural interventions that add feedback connections (activating an SFURTI cluster, building the co-op past critical mass) produce larger effects. The most powerful lever is not any single policy but the *structure* — the co-op crossing critical mass and the portfolio's delivery coherence — which changes the rules governing how policies interact, exactly as Meadows predicts.

> **References:** Meadows (1999, 2008).

7. D5 — Spatiotemporal Analysis

7.1 Tobler's First Law of Geography

The theory. Tobler (1970): "everything is related to everything else, but near things are more related than distant things" — the basis for spatial decay in policy reach, whether geographic, institutional, or infrastructural.

CPAF operationalisation. CPAF implements three context zones — urban (×1.0), peri-urban (×0.7), rural (×0.4) — applied to every policy's effectiveness, so the same national scheme delivers different outcomes by location. Urban Lucknow (Chikankari) receives full reach; rural Telangana (Cheriyal) only partial. Infrastructure improves dynamically with successful implementation, but the initial gap explains much of the differential effectiveness.

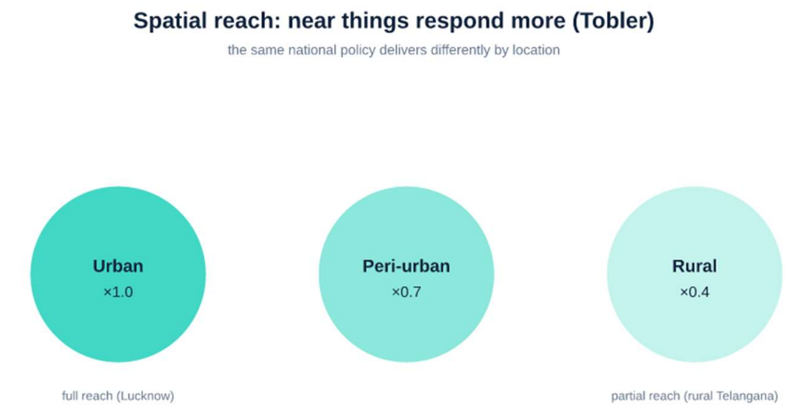

Figure 7: Spatial reach — urban, peri-urban, and rural modifiers on every policy effect.

> **Property:** geography as a structural moderator of effectiveness. **References:** Tobler (1970); Anselin (1988).

8. D6 — Agent-Based Modelling

8.1 ABM Foundations (Epstein & Axtell)

The theory. ABM (Epstein & Axtell, 1996; Gilbert, 2008; Bonabeau, 2002) builds system behaviour from heterogeneous agents with decision rules; system-level patterns emerge from the aggregate rather than being imposed. Its distinctive contribution is heterogeneity.

CPAF operationalisation. CPAF implements a lightweight agent layer governing artisan entry and exit around the income thresholds — the Harris–Todaro (1970) migration logic, in which the income differential drives movement into and out of the craft, producing the population dynamics and the skilled-artisan drain of a declining trade rather than assuming them. Segments differ in their position in the value chain and hence in the policy benefit they capture; a Gini coefficient tracks the resulting inequality. A key emergent finding: policies that raise average income can raise inequality by favouring the best-positioned segment, shifting narratives and eventually constraining the very policies that were working — an outcome that arises from the ABM–NPF coupling, not from any single rule.

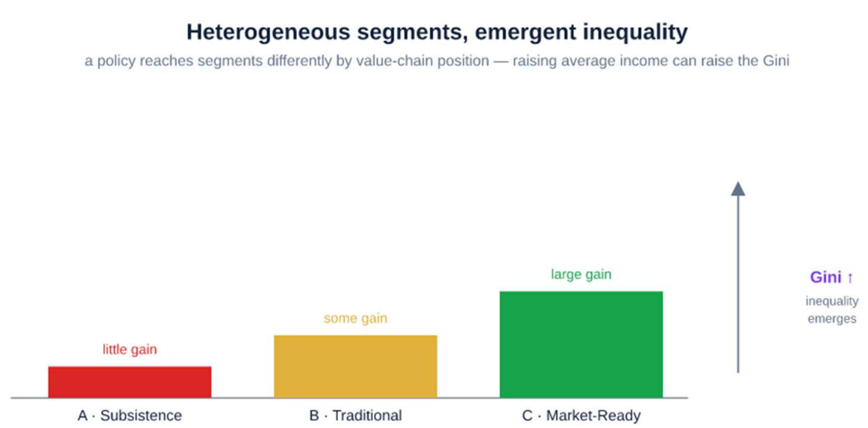

Figure 8: Heterogeneous segments and the emergence of inequality.

> **Property:** emergent inequality dynamics from heterogeneous impact. **References:** Epstein & Axtell (1996); Gilbert (2008); Bonabeau (2002); Harris & Todaro (1970).

9. D7 — Monte Carlo Simulation

9.1 Monte Carlo Methods and Sensitivity Analysis

The theory. Monte Carlo simulation (Metropolis & Ulam, 1949; Saltelli et al., 2004, 2008) uses repeated random sampling to produce distributions of outcomes with confidence intervals, revealing which results are robust and which are sensitive; global sensitivity analysis (Sobol, 2001) identifies which parameters drive output variance.

CPAF operationalisation. D7 wraps the simulation in a Monte Carlo envelope: each scenario runs many times under stochastic variation, and CPAF reports a *reliability* (the share of runs that escape) and a *range*, never a single deterministic figure. This is the operational reason the model must not be read as a forecaster. The in-model robustness test (validation test B7) perturbs all parameters by ±15% and confirms the qualitative conclusions survive; the fuller one-at-a-time sweep (§15) extends this across every parameter's full range.

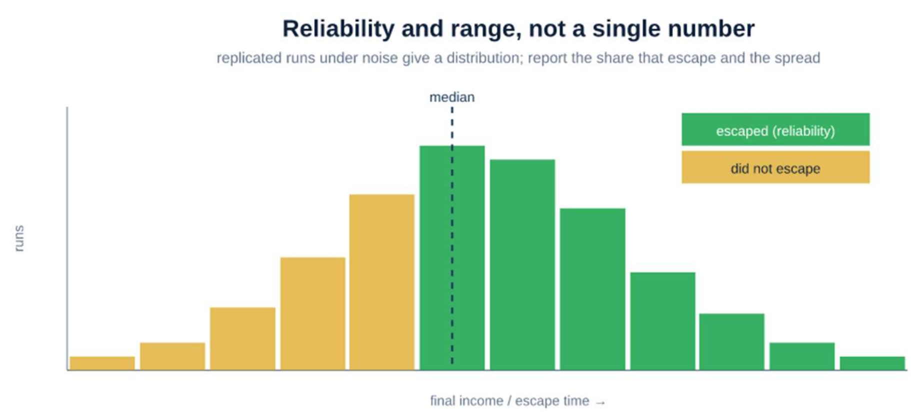

Figure 9: Monte Carlo — a distribution of outcomes, reported as reliability and range.

> **Property:** honest uncertainty quantification; distinguishing structural from stochastic outcomes. **References:** Metropolis & Ulam (1949); Saltelli et al. (2004, 2008); Sobol (2001); Barlas (1996).

10. Cross-Dimension Couplings

The bidirectional couplings connecting CPAF's dimensions are not arbitrary wiring; each is a theoretically grounded causal mechanism. Representative couplings:

Coupling	Mechanism	Theory	Emergent property
D1 ↔ D2	delivery coherence affects basin depth; regime stress strains ties	Granovetter (1973); Scheffer (2009)	resilience depends on both structure and regime
D1 ↔ D3	the co-op enables collective voice; narratives shape willingness to coordinate	Sabatier (1988); Shanahan et al. (2018)	coalition–coordination feedback

Coupling	Mechanism	Theory	Emergent property
D2 ↔ D3	crisis generates urgency narratives; narratives set which equilibrium is acceptable	Baumgartner & Jones (2009); Jones & McBeth (2010)	narrative lock-in reinforces regime lock-in
D1 ↔ D4	coherence scales policy reach; SD outcomes update coordination incentives	Rhodes (1997); Sterman (2000)	effectiveness depends on structure, not just design
D2 ↔ D4	income sets the regime; the regime sets which loops dominate	Azariadis & Stachurski (2005); Sterman (2000)	same policy, different outcome by state
D3 ↔ D4	feasibility gates activation; outcomes shift narratives	Kingdon (1984); May (1986)	policy windows open and close on outcome feedback
D5 → D1	geography constrains tie formation	Tobler (1970); Granovetter (1973)	spatial context sets the coordination ceiling
D5 → D4	spatial modifiers scale all flow rates	Tobler (1970); Anselin (1988)	same policy, different geography, different outcome
D6 ↔ D4	segments receive differential outcomes; aggregate behaviour feeds stocks	Epstein & Axtell (1996); Sterman (2000)	heterogeneous impact and emergent inequality
D1 ↔ D6	network position shapes policy benefit	Granovetter (1973); Epstein & Axtell (1996)	structural inequality from position
D3 ↔ D6	segments hold different narratives; dominance reflects segment power	Jones & McBeth (2010); Gilbert (2008)	endogenous coalition composition

Within the D1 couplings the model separates the **co-op** (a producer-side lever) from **delivery coherence, C_eff** (the state-side multiplier); Figure 1 should be read with that two-stream distinction in mind.

11. Public Policy Dynamics: How Policy Lives in the Model

The dimensions and couplings describe the *system* a policy acts on. This section describes the *policy itself* — how a public policy enters the model, accumulates force, matures, and fades, and why the model treats a policy as a living process rather than a switch. For a public-policy audience this is the heart of the framework, so the mechanisms are gathered here even though several also appear under the dimensions above.

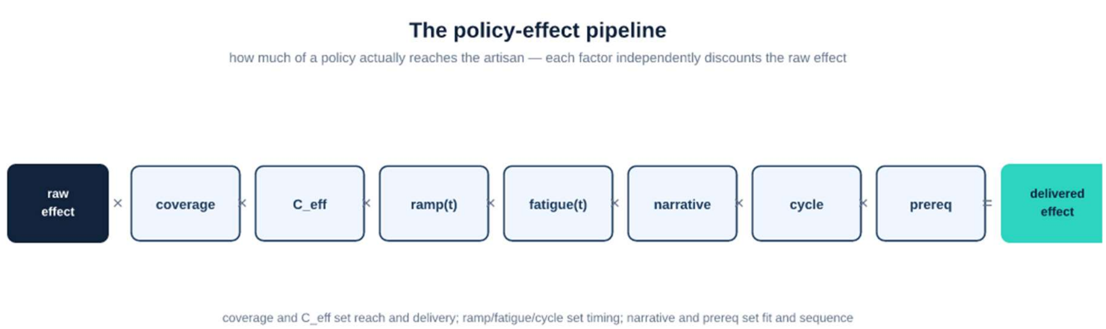

Figure 10: The policy-effect pipeline — how a raw policy effect becomes a delivered one.

11.1 The policy-effect pipeline

No policy in CPAF acts at full strength the moment it is switched on. Each active policy's raw effect is passed through a multiplicative pipeline, and every factor independently discounts or amplifies it:

delivered effect = raw effect × coverage × C_eff × ramp(t) × fatigue(t) × narrative alignment × political-cycle modifier × prerequisite modifier.

This is the model's answer to a question single-lens analysis rarely asks: *not whether a policy is good on paper, but how much of it actually reaches the artisan.* Coverage sets the share of the population it can touch; delivery coherence (C_eff) sets how much survives inter-ministry friction; the remaining factors — described below — encode the policy's own life in time and politics.

11.2 The policy lifecycle: ramp-up, maturity, and fatigue

A policy's reach follows an S-curve, not a step. On activation it delivers only a fraction of its eventual effect; the sigmoid ramp climbs toward full strength over a maturation period specific to each instrument (from immediate for a price signal to eighteen months for an institution-building scheme). This is the "stock" character of policy: effect *accumulates* like a stock filling, rather than switching on.

At the other end of the life, effect **fatigues**. Following Kingdon's (1984) insight that policy windows close, an instrument left active too long loses potency — attention drifts, administrative energy wanes, novelty fades — and its modifier decays toward a floor. A policy is therefore strongest in its middle life, weak at both ends: the model reproduces the practitioner's experience that neither a brand-new nor a long-stale scheme delivers what a mature one does.

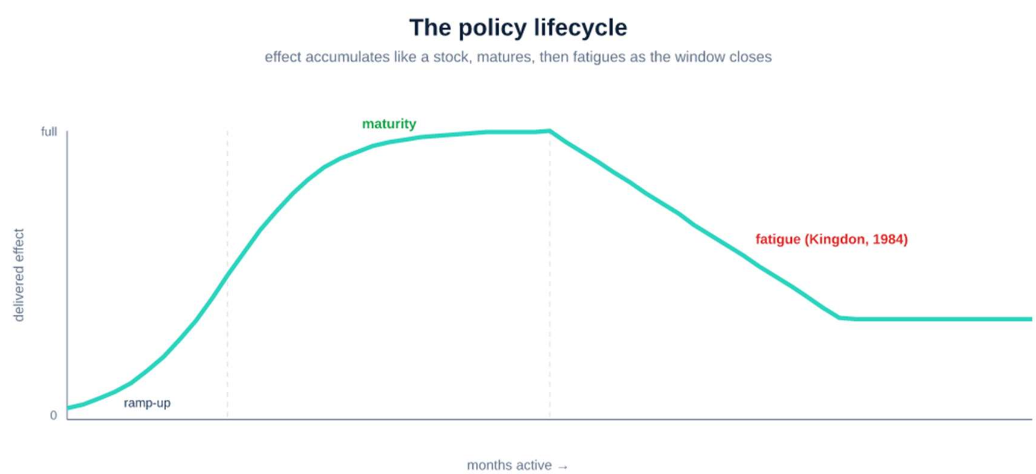

Figure 11: The policy lifecycle — sigmoid ramp-up to maturity, then fatigue as the window closes.

11.3 Sequencing and path dependence

Policies are not independent. Through **prerequisites**, an instrument is more effective when an enabling policy is already mature, and weaker without it — an e-commerce push lands harder once GI registration and cluster development are in place, and underperforms in a vacuum. This operationalises Howlett and Rayner's (2007) work on policy mixes and sequencing and Pierson's (2000) path dependence: the *order* in which policies mature, not merely their presence, shapes the outcome. It is why the model can show that the same portfolio, sequenced differently, escapes or stalls.

11.4 Feasibility gates

Not every technically sound policy can be activated. A feasibility gate, driven by the political-feasibility state, blocks policies outside the prevailing window: welfare instruments are blocked when the political environment tilts strongly to the market, market instruments when it tilts strongly to welfare, and structural instruments when coordination is below the threshold at which they can even form. This encodes political-feasibility analysis (May, 1986; Meltsner, 1972; Kingdon, 1984): merit is necessary but not sufficient for a policy to act.

11.5 Mapping onto the policy cycle

The mechanisms above map recognisably onto the classic policy cycle (Lasswell; Howlett & Ramesh), and it is worth stating honestly which stages the model represents strongly and which only implicitly. **Formulation and adoption** are represented through the feasibility gates and coalition/narrative states; **implementation** is the model's strongest stage — the ramp-up, coverage, delivery coherence, and fatigue are all implementation dynamics; **evaluation** is represented through the outcome metrics (income, inequality, escape reliability) that feed back into narratives and feasibility. **Agenda-setting** is the most implicit — it enters only through narrative shifts and focusing events, not as a distinct stage. The model is thus best read as an *implementation-and-feedback* instrument within the cycle, not a complete agenda-to-evaluation simulator — a scope choice stated openly.

> **Dimensions:** primarily D3 and D4, gating D1. **Mechanism:** multiplicative policy-effect pipeline with lifecycle, sequencing, and feasibility. **Property captured:** policy as a time- and politics-dependent process, not a switch. **References:** Kingdon (1984); Howlett & Rayner (2007); Pierson (2000); Baumgartner & Jones (1993); May (1986); Meltsner (1972).

12. Engineering Complexity and Stochastic Behaviour

Section 2 set out the *theories* of complexity that justify the model's design. This section is different in kind: it explains *how those theories were turned into working machinery* — the concrete, deliberate mechanisms that make CPAF behave as a complex, non-stationary, stochastic system rather than a smooth deterministic one. A linear model would produce clean, repeatable curves; real policy systems do not, and the following devices are how the model earns its complexity honestly.

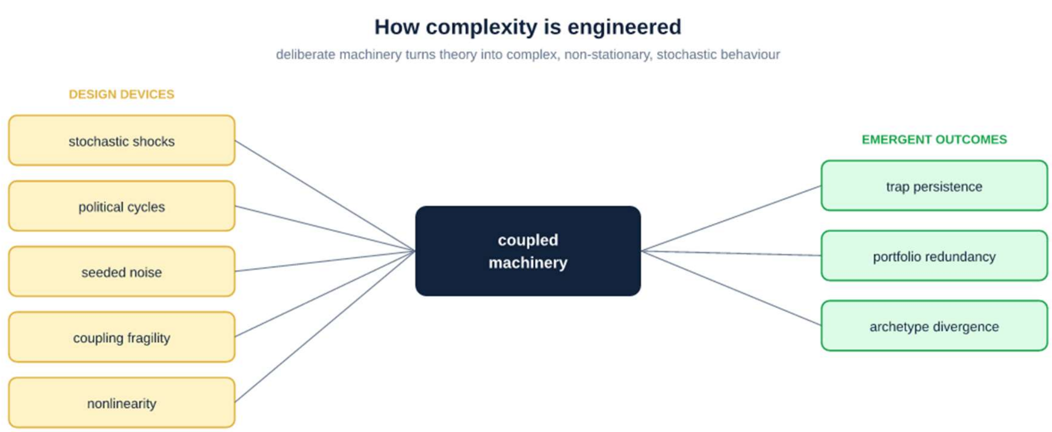

Figure 12: How complexity is engineered — shocks, cycles, noise, and coupling combine to produce emergent behaviour.

12.1 Stochastic shocks

The world is not stationary, so the model is not either. A stochastic shock process injects episodic disruptions — monsoon failures, demand slumps, input-cost spikes, demonetization- and COVID-like discontinuities — at a low monthly probability (roughly one shock every two years), with a deliberately slow recovery. Crucially, vulnerability is **regime-dependent**: a system in the TRAP is more fragile and recovers more slowly than one in GROWTH, so the same shock that a healthy cluster absorbs can push a fragile one further down. Shocks are the model's main source of run-to-run variation and the reason a single run is a draw, not a destiny.

Figure 13: The stochastic shock system — episodic disruptions with regime-dependent fragility.

12.2 Political attention cycles

Policy effectiveness also varies *cyclically*. A political attention cycle modulates delivery over an electoral-style period — attention and implementation energy rise and fall, with an implementation dip at predictable points. Grounded in Kingdon (1984) and Baumgartner and Jones (1993), this makes the timing of a policy relative to the political calendar matter, and adds a second, structured source of non-stationarity distinct from random shocks.

12.3 Stochastic noise and reproducibility

Beneath the discrete shocks, continuous low-amplitude noise perturbs the system each month, so no two runs trace the identical path. This is what makes reliability-and-range reporting meaningful rather than decorative. The noise is driven by a **seeded** pseudo-random generator (mulberry32), reset at the start of every run: the model is stochastic *and* reproducible — a given seed reproduces a given run exactly, which is what allows honest A/B comparison and calibration. Stochasticity without reproducibility would be unscientific; the seed resolves the tension.

12.4 Coupling density and fragility

Complexity is not free. The same runtime couplings that let the dimensions inform one another also transmit disruption: the tighter the coupling, the faster a shock in one dimension propagates to the others. The model encodes this as a fragility relationship — higher coupling density raises efficiency but also vulnerability — echoing Perrow's (1984) normal-accident theory, in which tightly coupled systems are more prone to cascading failure. It is a deliberate, honest cost of the integrated architecture, not a flaw to hide.

12.5 Nonlinearity and emergence

Finally, the model is nonlinear by construction: sigmoid diffusion, threshold-gated regime transitions, hysteresis, and path-dependent prerequisites mean that identical inputs can yield qualitatively different outcomes depending on the system's state and history. It is the interaction of these devices — shocks landing on a fragile regime, cycles coinciding with immature policies, noise nudging a system near a threshold — that produces genuine **emergence**: outcomes such as trap persistence, portfolio redundancy, and archetype divergence that were not written into any single rule but arise from the machinery working together. The validation suite (§14) exists precisely to confirm that this engineered complexity behaves soundly rather than chaotically.

> **Dimensions:** all, via the complexity layer. **Mechanism:** stochastic shocks, political cycles, seeded noise, coupling-density fragility, and pervasive nonlinearity. **Property captured:** non-stationarity, regime-dependent fragility, reproducible stochasticity, and emergence. **References:** Perrow (1984); Kingdon (1984); Baumgartner & Jones (1993); Holland (1995); Scheffer (2009).

13. Theoretical Novelty of CPAF v6

The novelty is not in any single theory — all are established — but in three innovations.

13.1 Runtime coupling of seven analytical dimensions. Existing computational policy tools typically employ one or two methods — system dynamics alone (Vensim), ABM alone (NetLogo), network analysis alone (Gephi). CPAF is, to the author's knowledge, the first framework to achieve *runtime bidirectional coupling* across seven distinct dimensions: not seven analyses reported side by side, but each dimension's output modifying the others' behaviour at every timestep.

13.2 Value-chain architecture as a mediating variable — and two archetypes of failure. The two case studies show that identical national policies produce structurally different outcomes depending on a cluster's value-chain architecture. The model distinguishes two diagnosable archetypes: a **distributional failure** (a monopsony trap, where value exists but is captured, requiring a structural bundle — the co-op *and* a market channel, an AND-gate — to break the grip) and a **connective failure** (a viable craft cut off from the market, responding to a single market-linkage lever). Both are bistable; the contribution is that the *diagnosis* dictates the *lever*, which single-lens analysis cannot see.

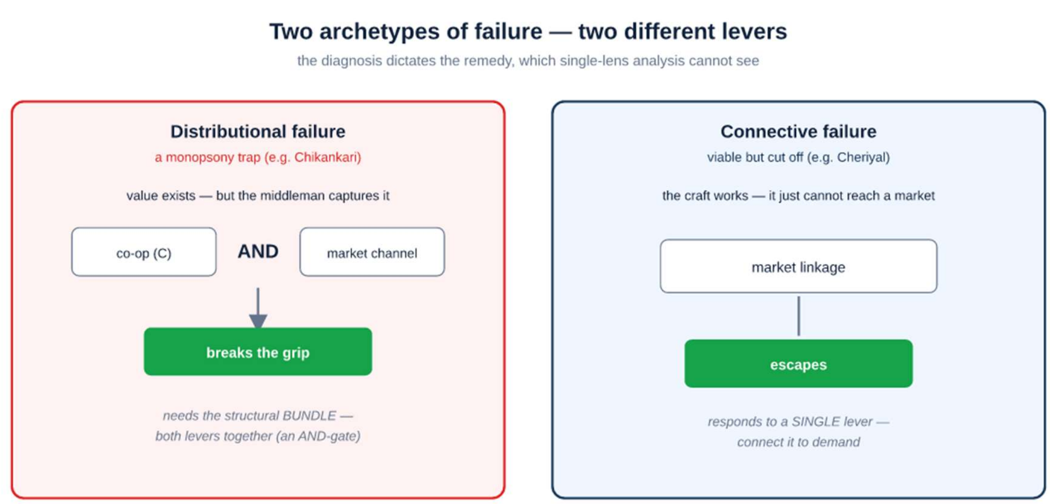

Figure 14: Two archetypes of failure, two different levers.

13.3 Honest uncertainty architecture. With roughly 61% of parameters classified as declared assumptions, CPAF does not claim predictive accuracy. It instead demonstrates an honest uncertainty architecture: every parameter is classified by provenance, the model reports reliability and ranges rather than points, and a full validation suite and parameter sweep (below) test whether the conclusions survive the softness of the numbers. Disclosing parameter provenance at all is itself uncommon in computational policy modelling.

14. Validation

CPAF is validated as a theory-driven structural model, following the subset of the Barlas (1996), Forrester–Senge (1980) and Sargent (2013) tests appropriate to a model with declared parameters. Tests requiring empirical time-series or predictive fit are deliberately excluded — they do not apply to a reasoning instrument. The suite runs in three stages across three regimes, so a pass is a property of the structure, not one calibration. **Result: 15/15 structural tests and 6/6 demonstration tests — 21/21.**

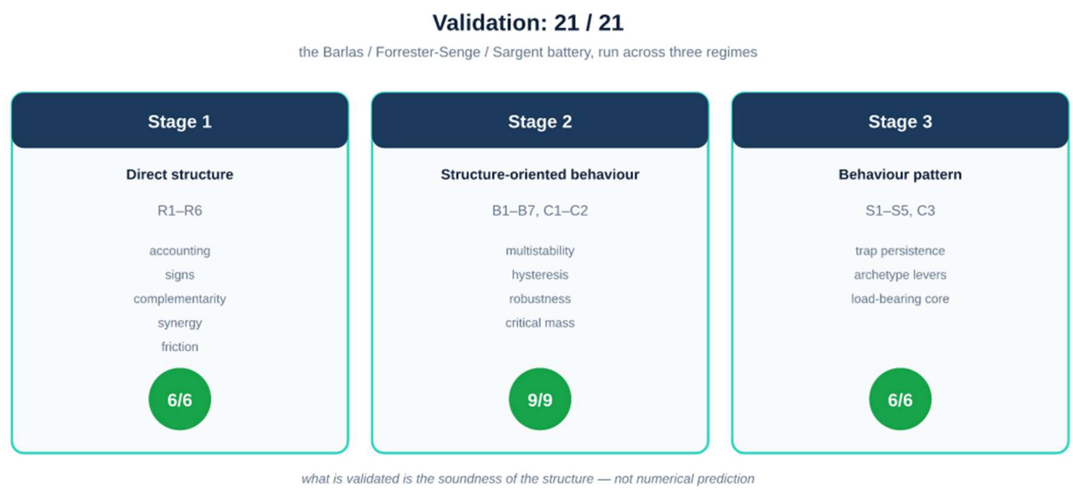

Figure 15: The three-stage validation structure and its results.

- **Stage 1 (direct structure):** conservation, boundedness, correct signs of extraction, complementarity, synergy, and fragmentation friction (R1–R6).
- **Stage 2 (structure-oriented behaviour):** multistability, threshold classification, ordered transitions, hysteresis, gradual response, bounded convergence, ±15% stochastic robustness, a coordination critical-mass threshold, and robustness across the admin grid (B1–B7, C1–C2).
- **Stage 3 (behaviour pattern):** poverty-trap persistence, integration beating single-stance, the connective case responding to market linkage, the distributional case responding to structural policy, archetype divergence, and the load-bearing-core portfolio structure (S1–S5, C3).

The connective-failure case (Cheriyal) is bistable and responds to market linkage (validation test S3); full details are in the Validation Report.

15. Sensitivity and Robustness

Because roughly 61% of parameters are declared assumptions, the model is stress-tested to establish that its *conclusions* do not depend on any single soft number. A one-at-a-time sweep takes each of the 28 ranged parameters to both extremes of its own declared range; five core conclusions are re-checked at each setting. **Each conclusion holds across 55 of 56 parameter-extremes — 98% robust.** The few breaks occur only at degenerate values (a destitution floor set above the poverty line; an earning ceiling below subsistence) that no reasonable calibration would adopt.

The decisive observation: the parameter that moves the income *level* most (the headroom term) barely touches the *conclusions*. The numbers are soft; the structural conclusions are firm. This is the property a reasoning instrument should have and a forecaster cannot afford. The global complement is validation test B7 (±15% all-parameter Monte Carlo). Full details are in the Sensitivity & Robustness Analysis.

16. Provenance and Epistemic Honesty

Every parameter is classified by the strength of its grounding: approximately **3% empirical, 9% mechanism-grounded, 27% literature-grounded, and 61% declared assumptions** with, usually, a theory-based equation form. The theory in this companion justifies the *form and direction* of each relationship; it rarely fixes the exact number — which is why the model reports reliability and ranges, and why §§14–15 matter.

Two anchors reduce the assumption load where evidence exists. The income thresholds are tied to documented poverty and consumption lines (World Bank $2.15/day and $3.00/day; India HCES 2023-24), so the trap and growth lines are not invented. The validation standard is the established Barlas battery. Neither makes the assumptions true; both make the reasoning honest. The two case studies are demonstration instances: their starting values are illustrative and source-informed — the Chikankari case, for example, draws on Singh and Shah (2023) — rather than validated calibrations or forecasts.

A note on method: this framework was developed with AI assistance under a citation discipline, and all references were verified against source. The framework, the theoretical choices, and the judgement are the author's, and responsibility for the work rests with the author.

17. Reference List

How to read this. The table below maps the references **operationalised in the model** to where each is used; the **full reference list** follows it. References follow APA 7th-edition style, with DOIs where available.

Operationalised in the model — where each reference is used

Reference	Where in the model	Role
Granovetter (1973)	D1 — market linkage / weak ties	cross-cluster bridges carry information
Granovetter (1978)	D1 / test C1 — co-op critical mass	threshold for collective action
Peters (2015)	D1 — the C_eff multiplier	inter-ministry delivery coherence
Bardhan (2002)	D1 — coordination across levels	decentralised governance

Reference	Where in the model	Role
Scheffer et al. (2001); Scheffer (2009)	D2 — regime transitions, hysteresis	critical transitions and early warning
Azariadis & Stachurski (2005)	D2 / D4 — the TRAP attractor	self-reinforcing poverty-trap equilibrium
Holling (1973)	D2 — hysteresis / resilience	why a brief crossing is not escape
Meadows (1999, 2008)	D4 — leverage-point hierarchy	structure beats parameter tweaks
Jones & McBeth (2010)	D3 — the narrative state variable	narrative shapes feasibility (NPF)
Sabatier (1988)	D1 ↔ D3 — coalition / feasibility state	advocacy-coalition dynamics
Kingdon (1984)	§11 — feasibility gates & policy fatigue	windows open and close
Baumgartner & Jones (1993)	D2 & §12 — punctuation, attention cycle	discontinuous change; cyclical attention
Birkland (1998)	§12 — focusing events	shocks that reset the agenda
Sterman (2000); Forrester (1961)	D4 — the stock-and-flow engine	system-dynamics backbone
Anselin (1988); Tobler (1970)	D5 — spatial modifiers (×1.0/0.7/0.4)	non-uniform, decaying reach
Epstein & Axtell (1996); Schelling (1971)	D6 — agent entry/exit rules	emergent behaviour from agents
Harris & Todaro (1970)	D6 — income-differential migration	artisan entry and the skilled drain
Saltelli et al. (2008)	D7 & test B7 — sensitivity	global sensitivity / robustness
Metropolis & Ulam (1949)	D7 — the Monte Carlo envelope	reliability and range, not points
Ostrom (1990)	D1 — the artisan co-op	institutional basis of collective action
Olson (1965)	D1 / T7 — inequality erodes the co-op	the logic of collective action
Gereffi et al. (2005)	value chain — middleman betweenness	value-chain governance and capture
Galbraith (1952)	co-op vs middleman	countervailing power
Perrow (1984)	§12 — coupling-density fragility	tight coupling → cascading failure
Kotler & Keller (2016)	complexity — demand saturation	ceiling on income growth
Howlett & Rayner (2007)	§11 — prerequisites / sequencing	policy mixes and sequence
Pierson (2000)	§11 — prerequisite path dependence	increasing returns / lock-in
Wilkinson-Weber (1999); Liebl & Roy (2003); Harriss-White (2003); Breman (2013); Scrase (2003)	case grounding — extraction & sector	documented handicraft dynamics
UNESCO (2003)	heritage stock	craft skill as intangible heritage
Barlas (1996); Forrester & Senge (1980); Sargent (2013)	§14 — validation suite	the validation standard

Threshold anchoring (empirical): the destitution and poverty lines follow the World Bank international poverty lines — $2.15/day 2017 PPP and $3.00/day 2021 PPP (Foster et al., 2025; World Bank, 2025) — consistent with the Rangarajan Committee (2014) rural line; the viability line follows rural monthly per-capita consumption from the Household Consumption Expenditure Survey 2023–24 (National Sample Survey Office, 2024).

References

1. Anselin, L. (1988). Spatial econometrics: Methods and models. Kluwer Academic.
2. Azariadis, C. & Stachurski, J. (2005). Poverty traps. In Handbook of Economic Growth, 1, 295–384. Elsevier. https://doi.org/10.1016/S1574-0684(05)01005-1
3. Banerjee, A.V. & Duflo, E. (2011). Poor economics. PublicAffairs.
4. Bardhan, P. (2002). Decentralization of governance and development. Journal of Economic Perspectives, 16(4), 185–205. https://doi.org/10.1257/089533002320951037
5. Barlas, Y. (1996). Formal aspects of model validity and validation in system dynamics. System Dynamics Review, 12(3), 183–210. https://doi.org/10.1002/(SICI)1099-1727(199623)12:3<183::AID-SDR103>3.0.CO;2-4
6. Barrett, C.B. & Carter, M.R. (2013). The economics of poverty traps and persistent poverty. Journal of Development Studies, 49(7), 976–990. https://doi.org/10.1080/00220388.2013.785527
7. Baumgartner, F.R. & Jones, B.D. (1993). Agendas and instability in American politics. University of Chicago Press.
8. Birkland, T.A. (1998). Focusing events, mobilization, and agenda setting. Journal of Public Policy, 18(1), 53–74. https://doi.org/10.1017/S0143814X98000038
9. Bonabeau, E. (2002). Agent-based modeling. PNAS, 99(suppl 3), 7280–7287. https://doi.org/10.1073/pnas.082080899
10. Borgatti, S.P. & Halgin, D.S. (2011). On network theory. Organization Science, 22(5), 1168–1181. https://doi.org/10.1287/orsc.1100.0641
11. Breman, J. (2013). At work in the informal economy of India. Oxford University Press.
12. Byrne, D. & Callaghan, G. (2014). Complexity theory and the social sciences. Routledge.
13. Cairney, P. (2012). Complexity theory in political science and public policy. Political Studies Review, 10(3), 346–358. https://doi.org/10.1111/j.1478-9302.2012.00270.x
14. Dakos, V., et al. (2012). Methods for detecting early warnings of critical transitions in time series illustrated using simulated ecological data. PLoS ONE, 7(7), e41010. https://doi.org/10.1371/journal.pone.0041010
15. Eldredge, N. & Gould, S.J. (1972). Punctuated equilibria. In Models in Paleobiology, 82–115. Freeman Cooper.
16. Epstein, J.M. & Axtell, R.L. (1996). Growing artificial societies. MIT Press.
17. Forrester, J.W. (1961). Industrial dynamics. MIT Press.
18. Forrester, J.W. & Senge, P.M. (1980). Tests for building confidence in system dynamics models. TIMS Studies, 14, 209–228.
19. Foster, E. M., Jolliffe, D., Ibarra, G. L., Lakner, C., & Tetteh-Baah, S. K. (2025). Global poverty revisited using 2021 PPPs and new data on consumption (Policy Research Working Paper 11137). World Bank. https://doi.org/10.1596/1813-9450-11137

20. Galbraith, J.K. (1952). American capitalism: The concept of countervailing power. Houghton Mifflin.
21. Gereffi, G., Humphrey, J. & Sturgeon, T. (2005). The governance of global value chains. Review of International Political Economy, 12(1), 78–104.
22. Gilbert, N. (2008). Agent-based models. SAGE.
23. Granovetter, M.S. (1973). The strength of weak ties. American Journal of Sociology, 78(6), 1360–1380.
24. Granovetter, M.S. (1978). Threshold models of collective behavior. American Journal of Sociology, 83(6), 1420–1443. https://doi.org/10.1086/226707
25. Granovetter, M.S. (1983). The strength of weak ties: A network theory revisited. Sociological Theory, 1, 201–233.
26. Gunderson, L.H. & Holling, C.S. (2002). Panarchy. Island Press.
27. Harris, J.R. & Todaro, M.P. (1970). Migration, unemployment and development. American Economic Review, 60(1), 126–142.
28. Harriss-White, B. (2003). India working: Essays on society and economy. Cambridge University Press.
29. Holland, J.H. (1995). Hidden order. Addison-Wesley.
30. Holling, C.S. (1973). Resilience and stability of ecological systems. Annual Review of Ecology and Systematics, 4, 1–23.
31. Holling, C.S. (2001). Understanding the complexity of economic, ecological, and social systems. Ecosystems, 4, 390–405. https://doi.org/10.1007/s10021-001-0101-5
32. Howlett, M. & Rayner, J. (2007). Design principles for policy mixes. Policy and Society, 26(4), 1–18. https://doi.org/10.1016/S1449-4035(07)70118-2
33. Jones, M.D. & McBeth, M.K. (2010). A narrative policy framework: Clear enough to be wrong? Policy Studies Journal, 38(2), 329–353. https://doi.org/10.1111/j.1541-0072.2010.00364.x
34. Kenis, P. & Schneider, V. (1991). Policy networks and policy analysis: Scrutinizing a new analytical toolbox. In B. Marin & R. Mayntz (Eds.), Policy Networks: Empirical Evidence and Theoretical Considerations (pp. 25–59). Campus Verlag.
35. Kingdon, J.W. (1984). Agendas, alternatives, and public policies. Little, Brown.
36. Kotler, P. & Keller, K.L. (2016). Marketing management (15th ed.). Pearson.
37. Liebl, M. & Roy, T. (2003). Handmade in India. Economic and Political Weekly, 38(51/52), 5366–5376. https://www.jstor.org/stable/4414435
38. Mahajan, V. & Peterson, R.A. (1985). Models for innovation diffusion. SAGE Publications Inc.
39. Marsh, D. & Rhodes, R.A.W. (1992). Policy networks in British government. Clarendon. https://doi.org/10.1093/acprof:oso/9780198278528.001.0001
40. May, P.J. (1986). Politics and policy analysis. Political Science Quarterly, 101(1), 109–125.

41. Meadows, D.H. (1999). Leverage points: Places to intervene in a system. The Sustainability Institute.
42. Meadows, D.H. (2008). Thinking in systems: A primer. Chelsea Green.
43. Meltsner, A.J. (1972). Political feasibility and policy analysis. Public Administration Review, 32(6), 859–867.
44. Metropolis, N. & Ulam, S. (1949). The Monte Carlo method. Journal of the American Statistical Association, 44(247), 335–341.
45. Mitchell, M. (2009). Complexity: A guided tour. Oxford University Press.
46. Olson, M. (1965). The logic of collective action. Harvard University Press.
47. National Sample Survey Office. (2024). Survey on household consumption expenditure: 2023–24 (Report No. 589). Ministry of Statistics and Programme Implementation, Government of India. https://nccd.gov.in/uploads/Household_Consumption_Expenditure2023_24_d9fcc28952.pdf
48. Ostrom, E. (1990). Governing the commons. Cambridge University Press. https://doi.org/10.1017/CBO9780511807763
49. Ostrom, E. (2007). A diagnostic approach for going beyond panaceas. PNAS, 104(39), 15181–15187. https://doi.org/10.1073/pnas.0702288104
50. Perrow, C. (1984). Normal accidents: Living with high-risk technologies. Basic Books.
51. Peters, B.G. (2015). Pursuing horizontal management: The politics of public sector coordination. University Press of Kansas.
52. Pierson, P. (2000). Increasing returns, path dependence, and the study of politics. American Political Science Review, 94(2), 251–267. https://doi.org/10.2307/2586011
53. Rhodes, R.A.W. (1997). Understanding governance. Open University Press.
54. Rogers, E.M. (2003). Diffusion of innovations (5th ed.). Free Press.
55. Sabatier, P.A. (1988). An advocacy coalition framework of policy change. Policy Sciences, 21(2–3), 129–168. https://doi.org/10.1007/BF00136406
56. Sabatier, P.A. & Jenkins-Smith, H.C. (1993). Policy change and learning. Westview.
57. Saltelli, A., et al. (2008). Global sensitivity analysis: The primer. Wiley.
58. Sargent, R.G. (2013). Verification and validation of simulation models. Journal of Simulation, 7(1), 12–24. https://doi.org/10.1057/jos.2012.20
59. Scheffer, M., et al. (2001). Catastrophic shifts in ecosystems. Nature, 413, 591–596. https://doi.org/10.1038/35098000
60. Scheffer, M. (2009). Critical transitions in nature and society. Princeton University Press.
61. Scheffer, M., Bascompte, J., Brock, W. A., Brovkin, V., Carpenter, S. R., Dakos, V., Held, H., van Nes, E. H., Rietkerk, M., & Sugihara, G. (2009). Early-warning signals for critical transitions. Nature, 461(7260), 53–59. https://doi.org/10.1038/nature08227

62. Scheffer, M., et al. (2012). Anticipating critical transitions. Science, 338(6105), 344–348. https://doi.org/10.1126/science.1225244

63. Schelling, T.C. (1971). Dynamic models of segregation. Journal of Mathematical Sociology, 1(2), 143–186.

64. Scrase, T.J. (2003). Precarious production: globalisation and artisan labour. Third World Quarterly, 24(3), 449–461. https://doi.org/10.1080/0143659032000084401

65. Shanahan, E.A., Jones, M.D. & McBeth, M.K. (2018). The Narrative Policy Framework. In Theories of the Policy Process (4th ed.). Westview.

66. Singh, R. & Shah, P. (2023). Work profile and occupational hazards of Chikankari workers with special reference to Lucknow, North-Eastern India. The Pharma Innovation Journal, 12(1), 1276–1279.

67. Sobol, I.M. (2001). Global sensitivity indices for nonlinear mathematical models and their Monte Carlo estimates. Mathematics and Computers in Simulation, 55(1–3), 271–280. https://doi.org/10.1016/S0378-4754(00)00270-6

68. Sterman, J.D. (2000). Business dynamics. Irwin/McGraw-Hill.

69. Strogatz, S.H. (2015). Nonlinear dynamics and chaos (2nd ed.). Westview.

70. Tobler, W.R. (1970). A computer movie simulating urban growth in the Detroit region. Economic Geography, 46, 234–240.

71. True, J.L., Jones, B.D. & Baumgartner, F.R. (2007). Punctuated-equilibrium theory. In Theories of the Policy Process (2nd ed.). Westview.

72. UNESCO (2003). Convention for the Safeguarding of the Intangible Cultural Heritage. https://ich.unesco.org/en/convention

73. Walker, B., et al. (2004). Resilience, adaptability and transformability. Ecology and Society, 9(2), 5.

74. Weible, C.M., et al. (2011). A quarter century of the Advocacy Coalition Framework. Policy Studies Journal, 39(3), 349–360. https://doi.org/10.1111/j.1541-0072.2011.00412.x

75. Wilkinson-Weber, C.M. (1999). Embroidering lives. SUNY Press.

76. World Bank. (2022). Poverty and shared prosperity 2022: Correcting course. https://doi.org/10.1596/978-1-4648-1893-6

77. World Bank. (2025, June 5). June 2025 update to global poverty lines [Factsheet]. https://www.worldbank.org/en/news/factsheet/2025/06/05/june-2025-update-to-global-poverty-lines

Framework citation: Abboudi, B. (2026). Modelling Policy Complexity: A Computational Framework for Analysing Multi-Ministry Coordination in India's Handicrafts Sector (MA Public Policy thesis). O.P. Jindal Global University.