

The Delayed Reward Trap: A System Dynamics Archetype for Aspiration-Driven Livelihood Transitions and Its Application to Climate Adaptation Monitoring and Evaluation

Abstract

Monitoring and evaluation frameworks for climate adaptation in the Hindu Kush Himalaya face a structural problem: they are built on linear Theory of Change logic while the social-ecological systems they assess are governed by feedback, accumulation, and delay. This mismatch produces a systematic failure mode in which programs generating positive early indicators simultaneously erode the adaptive capacity that determines long-run welfare, a process invisible to standard monitoring until collapse is already underway.

This paper develops an operational M&E framework grounded in comparative case analysis from Nepal, Bhutan, and Myanmar, formalized through Systems Thinking and System Dynamics Modeling. Using Group Model Building, Causal Loop Diagram construction, and stock-and-flow simulation via Ventana System's Vensim[®], we identify a recurrent causal archetype, the Delayed Reward Trap, in which aspiration-driven livelihood transitions erode traditional adaptive capacity faster than new livelihoods generate compensatory income, producing Overshoot and Collapse in household welfare. Cross-case synthesis yields a 13-loop archetype with five reinforcing and seven balancing mechanisms, confirmed across all three cases despite profound differences in ecology, culture, and institutional context.

Four original theoretical contributions emerge: the distinction between cash-flow fragility (B2a and B2b, visible) and structural fragility (B3, latent until shock); the B4 vulnerability amplification polarity inversion across Nepal and Myanmar, demonstrating that "diversification reduces vulnerability" is context-dependent and is not sufficient alone to improve conditions; three structural inversions in Bhutan establishing conditional polarity reversal as a theoretical property of the archetype; and the R3↔B6 information bifurcation showing that information infrastructure is a delivery mechanism, not a policy instrument.

From this structural analysis, the framework derives three prescriptive design principles, Latency Matching, Pre-Loading Mandate, and Shadow Cost of Resilience Accounting, and two complementary M&E indicators: the Co-Scaling Index as a pre-failure leading indicator and the Gap Indicator as a concurrent early warning signal. These are delivered through a practitioner-accessible interactive simulation tool, developed for policy makers and practitioners like those at ICIMOD and applicable wherever the archetype's feedback structure governs livelihood transition dynamics.

1. Introduction

The IPCC's Sixth Assessment Report identifies South Asia as a climate change hotspot for risks to food security, public health, and migration, and documents a persistent gap between adaptation efforts and the scale of climate vulnerabilities, particularly across the Hindu Kush Himalaya (HKH), where national adaptation plans exist but their implementation and impact remain ambiguous (IPCC, 2022; Lei Win, 2022; Garimella and Prakash, 2023). Within this context, monitoring and evaluation frameworks occupy a critical but structurally underperforming role. They are the principal instruments through which adaptation investments are assessed and resource allocation decisions are made, yet existing M&E architectures are fundamentally mismatched to the dynamic complexity of the social-ecological systems they are designed to assess (Sterman, 2000).

The HKH region spans approximately 4.2 million km² across eight nations and sustains the freshwater needs of an estimated 1.9 billion people downstream through ten major river systems (Wester et al., 2019). Approximately 240 million people within the HKH depend directly on mountain and foothill resources for their livelihoods, food security, and cultural continuity (Wester et al., 2019). These systems face compounding climate stresses: rising temperatures alter crop calendars and accelerate glacial retreat; erratic precipitation undermines irrigation reliability; glacial lake outburst floods, seasonal river inundation, landslides, and the progressive upward shift of snow lines interact across multiple temporal scales to threaten both lives and productive systems (Bajracharya & Shrestha, 2011; Bajracharya et al., 2015; Wester et al., 2019). Increasing frequency of extreme events exposes

households to recurrent asset losses from which recovery is slow and partial (Hussain et al., 2016), and livestock illness driven by shifting disease vectors associated with warming temperatures is compounding the vulnerability of pastoral households (KC et al., 2022). Livelihood transitions, structured shifts from traditional agropastoral systems toward market-linked production, wage labor, or secondary vocations, have emerged as the central response strategy, supported by both community aspirations and significant programmatic investment. In Nepal, vegetable cash cropping has displaced subsistence grain cultivation in the mid-hills. In Myanmar, solar-linked agro-processing has restructured smallholder income strategies in upland communities. In Bhutan's dzongkhag districts, homestay tourism and urban employment have altered labor allocation and land use in ways that interact with traditional agropastoral systems unpredictably. Yet comparable communities following structurally similar interventions diverge sharply in outcomes in ways that neither hazard exposure nor income data alone can explain. From our own fieldwork and community-driven workshops, we have observed the role of community aspirations as well as natural hazards in shaping such shifts and their impacts, and the interplay of local and regional, social, ecological, and governance factors that drive such transitions and the distribution of their benefits and trade-offs in time and space.

The explanatory failure is structural. Existing M&E frameworks, whether sector-specific indicator sets, participatory vulnerability assessments, or Theory of Change templates, share an underlying epistemological assumption: that interventions operate through linear causal chains connecting inputs to outputs, and that tracking change along those chains provides a sufficient basis for learning (Lei Win, 2022; Sud et al., 2015). This assumption is analytically untenable in social-ecological systems characterized by feedback, accumulation, and delay (Sterman, 2000). The ambiguity that characterizes adaptation outcomes in HKH contexts is not primarily an information problem. It is a structural problem rooted in the mismatch between linear M&E logic and non-linear system behavior: the frameworks used to monitor and evaluate adaptation investments cannot see the processes that determine whether those investments enhance or undermine resilience.

The gap is, more precisely, a matter of rates. Social aspirations adjust upward in months; infrastructure commissions in years; adaptive capacity erodes over decades. M&E frameworks calibrated to annual reporting cycles cannot detect the divergence between these rates until collapse is already underway. When a development program accelerates livelihood transition faster than enabling infrastructure can be commissioned, the system overshoots: early income gains are real, but delayed costs accumulate invisibly, and the monitoring framework records progress precisely when structural fragility is growing. When a community shifts from diversified subsistence agriculture to specialized cash cropping, early income gains are rapid and visible. Traditional agronomic knowledge, seed varieties, and inter-household risk-sharing arrangements disappear gradually and invisibly. By the time a drought event triggers income collapse, the structural erosion that makes collapse severe and recovery slow has typically been operating for years — well outside the window within which early intervention would have been effective.

This paper develops an operational M&E framework that integrates resilience thinking into climate adaptation monitoring and evaluation in HKH communities. Drawing on comparative case analysis from Nepal, Bhutan, and Myanmar and employing grounded theory synthesis and system dynamics modeling, we identify a recurrent causal archetype, the Delayed Reward Trap, in which the same feedback structure generates recognizable behavioral signatures across structurally diverse empirical contexts.

The contribution is fourfold. Methodologically, cross-case archetype synthesis generates an empirically grounded causal framework from three field-based cases, reducing the modeling burden for M&E practitioners. Theoretically, the paper establishes aspiration, the forward-looking income and lifestyle targets that communities form in response to development opportunities and peer effects — as a dynamic behavioral control variable in social-ecological systems, introducing a formal mechanism connecting program design to adaptive capacity outcomes that existing resilience frameworks do not represent. Practically, it translates archetype structure into concrete M&E instruments: two complementary indicators, three-pathway decision logic, and an open interactive simulation tool, following the design philosophy of accessible policy simulation tools such as En-ROADS

(Stermann et al., 2020), developed in collaboration with ICIMOD and applicable wherever the archetype's feedback structure governs livelihood dynamics. Fourth, it derives three prescriptive design principles — Latency Matching, Pre-Loading Mandate, and Shadow Cost of Resilience Accounting — grounded in the archetype's feedback structure and offering testable hypotheses that conventional Theory of Change frameworks cannot generate. The framework's primary analytical contribution is the identification of aspiration as a dynamic behavioral variable that mediates whether climate adaptation investments build or erode community resilience, a mechanism invisible to conventional M&E practice.

2. Literature Review

Social-Ecological Systems Discourse and Resilience Theory

The sustainability of natural resource-based livelihoods like agriculture and livestock is best understood through the discourse of Social-Ecological Systems (SES) (Horcea-Milcu et al., 2020). SES discourse is inherently interdisciplinary, blending systems ecology, complex adaptive systems theory, and resource governance to explore the co-evolutionary dynamics between human societies and their biophysical environments. This framing has moved scholarship away from equilibrium-centric models toward representations that foreground adaptive capacity, self-organization, and cross-scale interaction (Colding and Barthel, 2019).

Central to this reorientation is resilience. Holling's (1973) foundational articulation established ecological resilience as the capacity of a system to absorb disturbance and reorganize while undergoing change. Folke et al. (2010) subsequently expanded this to encompass three interrelated capacities: absorbing shocks without crossing critical thresholds (robustness), adapting incrementally while remaining within the same basin of attraction (adaptability), and deliberately navigating transformation to an entirely new configuration when existing states become untenable (transformability). Applied to practical resource governance, SES tools have supported natural resource co-management, participatory monitoring, flexible institutional design, and structured social learning (Unnikrishnan et al., 2023; Ciftecioglu, 2018; Pahl-Wostl et al., 2018; Folke, 2016). However, the question remains how such a discourse can find its agency in policymaking given the ambiguity in the definition of SES, plurality in method, and reliance on place-based studies mostly from the Global North. The gap is wider for climate adaptation and development in fragile contexts of the Global South like the HKH region (Sud et al., 2015; Colding and Barthel, 2019; deVos et al., 2019; Chakraborty et al., 2023; Prakhyat and Prakash, 2023).

Monitoring and Evaluation and Theory of Change in Climate Adaptation

M&E serves three analytically distinct functions: ensuring accountability to funders and beneficiaries, supporting real-time program improvement, and generating learning about what works under what conditions (Howlett and Ramesh, 2003; Pahl-Wostl et al., 2007). M&E frameworks for climate adaptation follow the Theory of Change (ToC) approach, where goals for change, interventions, and outcomes are aligned and evaluated. Traditionally, ToC has favoured a linear, indicator-based approach measuring impacts as absolute changes across a specified period (Moxey et al., 1998), discounting complex dynamic inter-dependencies across space, sectors, and time (Pahl-Wostl et al., 2007; Hummelbrunner, 2011). What is required is a feedback-informed Theory of Change in which causal delays, loop dominance shifts, and threshold conditions are explicit monitoring elements rather than unstated assumptions.

ToC practice has been evolving toward landscape-level evaluation designs that accommodate indirect effects, co-produce indicators with stakeholders, and treat learning as an ongoing collective process (Reed et al., 2023). Vulnerability frameworks have decomposed system exposure into components of exposure, sensitivity, and adaptive capacity, each measured through proxy indicators (Gallopín, 2006). Yet such indices fail to reflect the dynamic nature of resilience, are scale-dependent, and are weak in exploration of complex causality responsible for emergent phenomena (Sharifi, 2016; Jones, 2019; Price, 2022). Indices describe states but cannot explain

mechanisms, they can indicate that adaptive capacity has declined without illuminating the feedback processes responsible or the leverage points through which intervention might be effective.

Systems Thinking and System Dynamics Modeling for Monitoring and Evaluation

System Dynamics Modeling (SDM) can help M&E processes understand the complexity and plurality of SES and design anticipatory policy interventions through scenario planning (Herrera de Leon and Kopainsky, 2019; Knight et al., 2019). A particularly significant development has been participatory systems modeling, which embeds stakeholder engagement directly into the model-building process, creating opportunities for stakeholders to learn from modeling as much as to plan practical interventions (Herrera de Leon and Kopainsky, 2020). The modeling process integrates: (1) co-production of knowledge around behavior over time of any social-ecological problem; (2) identification of the cause-effect-feedback loop structure governing that behavior; and (3) quantification of relationships using data from empirical research, expert opinion, and calibrated estimates to experiment with interventions in a simulation-based learning environment (Hovmand, 2014; Schluter et al., 2014; Varma et al., 2014; Vennix, 1996; Sterman, 2000). Such participatory modeling and scenario-based learning can engage a variety of stakeholders, facilitate social learning, and create confidence in the robustness and feasibility of proposed interventions (Checkland, 1999). Applying STSDM for M&E demands transdisciplinary capacities and resources that field practitioners rarely command, creating a need for an operational framework guiding M&E practitioners to integrate STSDM methods to track and manage SES resilience in the HKH, precisely where archetype analysis enters as a methodological bridge.

Archetype Analysis as the Methodological Bridge

Archetype analysis helps explore and identify the "recurrent patterns of variables and processes that shape the sustainability of SESs in different locations and times" (Oberlack et al., 2019). It functions as a boundary concept connecting deductive and inductive philosophies, multiple disciplines and their quantitative and qualitative methods, varying stakeholder worldviews, and the scales of knowledge generation and policy-making (Eisenack et al., 2019). A range of techniques — from grounded theory, qualitative comparative analysis (QCA), and meta-analysis to conceptual and participatory systems modeling — have been used for archetype analysis (Eisenack et al., 2019; Oberlack et al., 2019; Rocha et al., 2022; Aggarwal and Anderies, 2023). The use of archetypes to diagnose the causality of organizational failures and policy traps, and as starting points for simulation models, is already part of STSDM methodology (Senge, 2006).

Because archetypes operate at an intermediate level of abstraction, above the idiosyncratic detail of individual cases but below the universality of general theory, their construction requires careful navigation of the tension between abstraction and context-sensitivity (Eisenack et al., 2019; Ostrom et al., 2007). A fundamental limitation of existing archetype analysis, including canonical system archetypes (Senge, 2006), is that they are primarily descriptive, they explain recurrent failure but do not generate design rules. This paper extends archetype analysis into the prescriptive register, deriving from structural analysis three testable principles that specify when and how interventions can scale without producing fragility.

Synthesis: The Research Gap This Paper Addresses

SES and resilience theory has produced rich conceptual tools but lacks operationally accessible frameworks calibrated to Global South and HKH contexts. M&E practice has evolved toward greater sophistication but remains constrained by methods that cannot explain feedback-driven emergence. SDM offers exactly the analytical capability needed, but demands transdisciplinary resources that field practitioners rarely command. Archetype analysis provides a methodological pathway to generalize system dynamics insights across cases, but has not yet been synthesized into an operational M&E framework for the HKH, nor extended from description into prescription. This paper addresses that compound gap — constructing a transferable operational framework grounded in cross-case patterns from real community-level data, accompanied by an open interactive simulation

tool following the design philosophy of En-ROADS (Stermann et al., 2020) and applicable wherever the archetype's causal structure governs livelihood transition dynamics.

3. Methodology

This study blends grounded theory and STSDM to construct an operational M&E framework for policy interventions targeting livelihood transitions in HKH contexts — their benefits, trade-offs, and resilience implications. The overarching design pairs the inductive, context-sensitive logic of Grounded Theory (Glaser & Strauss, 1967) with the deductive, structurally rigorous logic of STSDM, moving from community-level evidence to generalizable structures without losing empirical grounding. Three steps operationalize this methodological blend.

Step 1: Situation Analysis and Group Model Building (GMB)

Situation analysis of natural resource management issues, climate change and policy impacts, and behavioural and landscape-level changes before and after interventions was conducted through fieldwork and content analysis. This identified shifts in livelihood practices, demarcated problem boundaries, and produced Behavior-Over-Time (BOT) graphs of key problem variables, the dynamic patterns of growth, decline, and collapse that the subsequent causal model must be capable of reproducing (Stermann, 2000). This was followed by Group Model Building (GMB) workshops with stakeholders in Myanmar, Nepal, and Bhutan, using the Causal Loop Diagram (CLD) tool of systems thinking (Herrera de Leon & Kopainsky, 2020). GMB is a facilitated, participatory, and iterative process in which affected communities, local practitioners, and policy stakeholders collaboratively construct shared representations of the systems in which they live and act (Vennix, 2009). CLDs constructed through GMB translate stakeholder narratives into a formal representation of the feedback architecture driving observed livelihood dynamics. Grounded Theory coding procedures (Glaser & Strauss, 1967) were then applied to synthesize findings across fieldwork data, workshop outputs, and narrative accounts, moving from specific observational codes to higher-order conceptual codes that identify recurrent structural patterns across cases.

Step 2: SDM Transformation and Grounded Theory Synthesis

The CLDs of the case studies were transformed into fully quantified System Dynamics Models (SDMs) through the five-step approach outlined in Stermann (2000): problem articulation, dynamic hypothesis formulation, model formulation, testing, and policy design and evaluation. Vensim (Ventana Systems) was used as the modeling platform. Scenario experiments for each country model examined the benefits and trade-offs of different livelihood shifts and mapped the conditions under which such shifts strengthen or undermine household resilience. A second Grounded Theory synthesis was then performed across the country-level CLDs, SDM outputs, and case-study narratives to identify concept-level variables, structural invariants across the three cases. This produced a summary-level CLD articulating the generic causal architecture of nature-based livelihood shifts in the HKH: a stylized representation of the feedback structures common to Myanmar, Nepal, and Bhutan that is neither reducible to any single case nor abstracted to the point of losing empirical purchase.

Step 3: Summary Model, Adaptation Pathways, and Practitioner Tool

The summary-level CLD was taken forward to a full system dynamics model using synthetic data, calibrated parameter estimates and theoretically grounded structural relationships. The use of synthetic data is methodologically justified when the purpose of modeling is theoretical rather than predictive: the goal is to reveal the dynamic implications of a posited causal structure, not to generate point forecasts for a specific location (Barlas, 1994).

The synthesis SFD is a theoretical instrument calibrated for qualitative behavioral plausibility rather than empirical prediction. Parameter values are synthetically derived from theoretical relationships and structural constraints

identified in the case CLDs; they have not been calibrated to field measurement data. Validation therefore proceeds through behavior-over-time pattern matching, confirming that the model generates the qualitative dynamic signatures (S-shaped growth, overshoot-and-collapse, aspiration ratchet behavior) observed across the three case SDMs, rather than through conventional goodness-of-fit testing (Barlas, 1994). Specific numerical thresholds produced by the SFD are structurally derived reference values, not empirically fitted constants, and require validation against field monitoring data before operational deployment. We are actively working with ICIMOD project managers to develop the tool further for practitioner use.

The synthesis SFD operationalizing the archetype CLD comprises seven stocks (Traditional Livelihood Households, New Livelihood Households, Enabling Infrastructure, Functional Infrastructure, Perceived Income, Social Aspiration Level, Adaptive Capacity), nine flows (Transition Rate, Reverse Transition, Construction, Commissioning, Functional Depreciation, Climate Destruction, Capacity Erosion, Capacity Regeneration, Aspiration Change), and auxiliary variables including Indicated Aspiration, Aspiration Gap Ratio, Aspiration Effect (Table 5-1), Infrastructure Productivity Effect, Macro Capacity Effect, and Climate Event Occurs. Complete formula derivations and theoretical citations — including Bass (1969) for Transition Rate, Sterman (2000, pp. 409–412) for infrastructure depreciation, Duesenberry (1949) and Kahneman and Tversky (1979) for the $\text{MAX}(0, \dots)$ ratchets, Genicot and Ray (2017) for the Aspiration Effect lookup, Herrera de Leon and Kopainsky (2019) for the Poisson hazard formulation, and Berkes and Turner (2006) for the asymmetric erosion-regeneration rates — are documented in Appendix A. The generic synthesis SFD uses baseline hazard frequency $\lambda = 0.3$ events/year; case-specific Nepal models use $\lambda = 0.3$ events/year derived from 16 documented major droughts between 1972 and 2016. Qualitative overshoot-and-collapse behavior is robust across this range. Scenario experiments inform adaptation pathways structured according to the Dynamic Adaptive Policy Pathways framework (Haasnoot et al., 2013), accessible through an open interactive simulation tool following the design philosophy of En-ROADS (Sterman et al., 2020) and applicable wherever the archetype's feedback structure governs livelihood dynamics.

Validation Approach

Given that the summary framework is theoretical in character, the appropriate mode of validation is theoretical structure verification rather than conventional empirical calibration (Barlas, 1994). The primary strategy is structural pattern matching: the dynamic behaviors generated by the summary model — most critically, the Overshoot and Collapse pattern of household economy trajectories — are compared against the analogous patterns produced by the country-level SDMs, which are themselves calibrated to empirical case-study data obtained from ICIMOD. The Nepal and Myanmar models both exhibit household economy collapse dynamics under livelihood stress; the Bhutan model captures yak population collapse as a proximate driver of household economy deterioration. The convergence of these distinct empirical trajectories on a common dynamic pattern provides the calibration anchor against which the summary model's theoretical structure is assessed. The three-step method yields a summary CLD and SFD (Sections 4–5), dynamic monitoring indicators (Section 6), and adaptation pathways delivered through the interactive practitioner tool (Section 6).

Expected Outputs

The three-step method yielded three interdependent outputs:

1. A cause-effect-feedback loop structure — a summary-level CLD and corresponding SDM representing the generic causal architecture of nature-based livelihood shifts, grounded in empirical evidence from Myanmar, Nepal, and Bhutan (Section 4–5).
2. A set of indicators operationalized as system dynamics elements — stocks, flows, and auxiliary variables — enabling continuous, dynamic monitoring of resilience-relevant system states in a form directly connected to the causal structure driving those changes (Section 6).

3. Adaptation pathways for managing resilience — anticipatory, conditional policy strategies derived from scenario experiments, structured according to the Dynamic Adaptive Policy Pathways framework (Haasnoot et al., 2013), and accessible through the interactive practitioner tool (Section 6).

4. Case Studies

Nepal — Resource-Limited Transition System

Context and Background

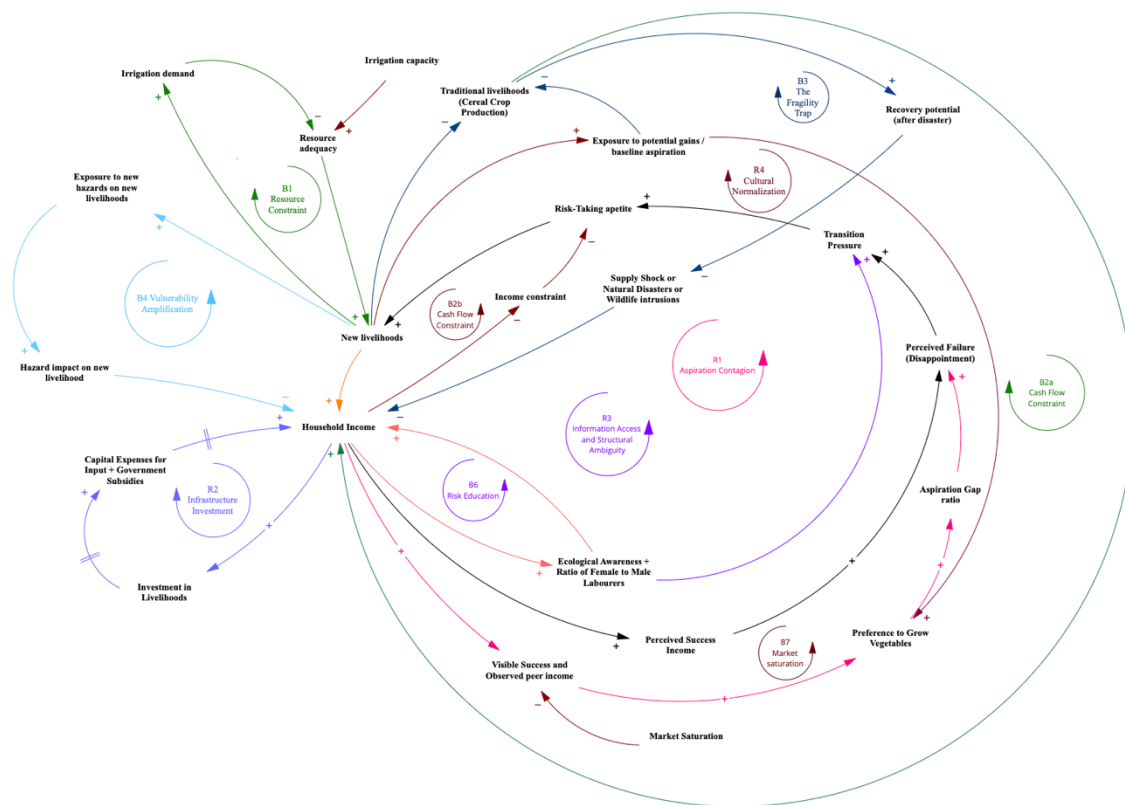
Nepal's unstable geology and fragile alpine ecosystem render it acutely susceptible to hydrometeorological hazards, including droughts and landslides, the frequency and severity of which are projected to intensify under anthropogenic climate change (Panthi et al., 2016). The Agricultural Perspective Plan (APP, 1995) laid the institutional foundation for agricultural commercialization by directing smallholder farmers away from subsistence-oriented cereal production toward higher-value cash crops, most notably vegetables (Brown & Kennedy, 2005). In Dadeldhura district, Sudurpashchim Province, land under vegetable production grew from 1,595 ha in 2010/11 to 2,447 ha by 2018/19 — a 53% increase — while vegetable output rose from 12,183 to 16,055 metric tons between 2010/11 and 2015/16 (Adhikari and Pandey, 2020). The four primary drivers identified through fieldwork were rising market demand, increased government subsidies, declining wildlife intrusion on vegetable crops, and male outmigration from farming households.

Nepal is simultaneously one of Asia's most drought-exposed countries. Traditional cereal crops carry low water sensitivity (heat resistance = 0.80); vegetables — cabbage, fresh greens, potatoes — fall in the medium-high to high sensitivity range (heat resistance = 0.40), such that a drought event destroys 60% of vegetable output but only 20% of cereal output per unit of disaster impact (FAO, n.d.; Karki, Mool, and Shrestha, 2010). Climate change is projected to further increase drought frequency (Karki et al., 2010), elevating the structural risk of a production system progressively shifting toward the more drought-sensitive crop.

Livelihood Shift

The economic rationale for transition was straightforward: vegetable crops generate substantially higher income per unit of land, and rising aspirations among farming households, shaped by exposure to market prices and the observable success of early adopters, reinforced this preference. What the income figures did not initially reveal was a consequential trade-off in adaptive capacity. As farmers progressively shifted land out of cereal production, they simultaneously abandoned the cultural practices, seed stocks, and risk-management strategies that had historically buffered households against climatic shocks. The erosion of these coping mechanisms did not register in standard livelihood indicators during the early phases of the transition, because household income was, by most measures, improving.

Causal Loop Structure (Initial)



The Nepal CLD, constructed from ICIMOD field data using Vensim, contains four reinforcing and seven balancing loops (Yu, 2021).

The dominant growth engine is R1 (Aspirational Contagion): rising household income increases visible peer success, elevates preference to grow vegetables, widens the aspiration gap, deepens perceived failure, amplifies transition pressure, raises risk-taking appetite, and drives new livelihood entry. R2 (Infrastructure Investment) deepens this through capital reinvestment into production expenses. R3 (Information Access) runs through Ecological Awareness and female labour participation, raising transition pressure directly. R4 (Cultural Normalization) operates through exposure to potential gains relative to baseline aspiration, bypassing the peer-income observation pathway, R5 of the archetype operates in Nepal through this R4 channel.

Three balancing loops set adoption ceilings. B1 (Resource Constraint) binds as irrigation demand approaches the fixed water capacity ceiling. B2a (Cash Flow Constraint) suppresses risk-taking as household income falls. B2b closes through perceived success: rising income reduces perceived failure and moderates transition pressure — a goal-seeking deceleration rather than direct startup cost, reflecting Nepal's case-specific income-satisfaction dynamic.

B3 (Fragility Trap) and B4 (Vulnerability Amplification) capture the collapse mechanism: traditional livelihood decline erodes recovery potential, while vegetable expansion increases drought exposure (case-specific vulnerability coefficients: vegetables 0.60, cereals 0.30). B6 (Risk Education) moderates R3 when ecological awareness is deliberately activated — Nepal's only programmatic B6 case. B5 (Market Saturation) is treated as exogenous, as district-level adoption does not move national vegetable prices.

Myanmar — Energy-Limited Transition System

Context

The Myanmar case focuses on Nyaungshwee Township, Shan State, within the ICIMOD Regional Land and Climate Change (RLACC) project. Rural livelihoods centre on subsistence and small-scale commercial agriculture, with a baseline population of 189,407 engaged in farming. Approximately 19,000 have already entered secondary vocations — baking, repair work, and micro-enterprises — yielding substantially higher returns (\$4.80/day for secondary work versus \$0.20/hour for farming; ICIMOD, 2019). The defining structural feature is energy poverty: fewer than 13% of rural households are connected to the national grid, with grid connection costing \$20,000 per community, prohibitive given Myanmar's poverty line of \$1.90 USD PPP/day (ICIMOD, 2019; ADB). Firewood gathering consumes 2 hours per day three times per week per household; water gathering an additional 2 hours per day (ICIMOD, 2019). Only 30% of the population is economically active, meaning labour time lost to subsistence energy collection directly compresses the income base. Declining rainfall and increasing hazard frequency, landslides and floods, further stress the agricultural sector (ICIMOD field validation).

The transition toward secondary vocations is not driven primarily by ecological pressure or government subsidy but by aspiration, expanding market access through phone penetration, and the hard ceiling of energy availability. As phone penetration rises, households gain exposure to market prices and online training platforms, generating aspiration that is moderated by the income gap, consistent with Flechtner's (2014) aspiration trap theory: when households fall below the poverty line, economic aspiration is suppressed even when transition pathways are nominally available. The rate of secondary vocation entry is jointly constrained by household income and energy availability, with excess energy consistently identified as the tighter binding constraint in Nyaungshwee, making energy poverty the dominant structural barrier to livelihood diversification rather than insufficient income support or inadequate aspiration.

Causal Loop Structure (Initial)

The Myanmar CLD, constructed from ICIMOD field validation data using Vensim, contains five reinforcing and six balancing loops. The dominant growth engine is R1 (Aspirational Contagion): rising household income increases visible success among secondary vocation holders, particularly visible against agricultural returns (\$4.80/day versus \$0.20/hour), elevating social aspiration, widening the aspiration gap, deepening perceived failure, amplifying transition pressure, and driving further secondary vocation entry. R2 (Infrastructure Investment) deepens this through income reinvested into solar panels and diesel generators, expanding productive capacity for secondary vocations. R3 (Information Access) runs through phone penetration: rising income enables mobile access, improving risk assessment of opportunities and accelerating transition pressure. R4 (Income Trajectory) captures resilience asymmetry: secondary vocations generate more stable income than primary farming, so adoption growth relaxes the income constraint and reinforces further entry. R5 (Cultural Normalization) operates through exposure to secondary vocation gains, normalizing secondary work independently of peer observation and reinforcing adoption through the aspiration-gap chain.

5. The Archetype CLD: Structure, Cross-Case Application, and SFD Integration

5. The Archetype CLD: Structure, Cross-Case Application, and SFD Integration

Livelihood transition in rural Himalayan and Southeast Asian households is a feedback-driven process in which aspiration, income, social learning, resource constraint, and physical hazard interact across multiple timescales to produce outcomes that frequently diverge, sometimes catastrophically, from the intentions of the households

experiencing them. Three characteristics motivate a system dynamics treatment: the forces driving transition are endogenous; the system is multi-loop with shifting dominance; and it contains structural fragility invisible in normal operating conditions, growth that appears as development success simultaneously undermines the resilience base that absorbs shocks.

The archetype CLD communicates model boundary decisions and makes causal polarities explicit prior to any functional specification (Sterman, 2000, Ch. 5). Figure 5-1 presents the full archetype. Two variables — Resource Limit and Market Saturation — are designated exogenous, as their dynamics exceed the household model boundary and must be analyzed through scenario perturbation. The archetype was derived inductively from the Nepal and Myanmar cases through the Grounded Theory synthesis described in Section 3, and subsequently cross-validated on Bhutan, a case selected because its surface structure diverges most sharply from the source cases. The loop descriptions below reflect the archetype as derived from the source cases; Bhutan-specific structural inversions are addressed in Part 2.

Variable Ontology

The 24 variables organize into four sectors. The Behavioral and Aspirational Sector (Social Aspiration level, Aspiration Gap ratio, Perceived Failure and Disappointment, Transition Pressure, Risk-Taking appetite, Perceived income trend, Visible Success and Observed peer income) operationalizes a canonical gap-closing structure (Forrester, 1968; Sterman, 2000): the household is an aspiration-follower, not a utility maximizer, whose income target rises with the observable success of others (Duesenberry, 1949). Critically, aspirations resist downward adjustment, Bernard and Taffesse (2014, Table 5, p. 150) document that income fell 30% but aspirations fell only 5% during the 2002–2004 Ethiopian drought, confirming the asymmetric ratchet structurally essential to the Delayed Reward Trap.

The Livelihood and Income Sector (Household Income, New and Traditional livelihoods, Traditional livelihoods' share in economy, Investment in Livelihoods) contains the temporal asymmetry driving B2a and B2b: traditional income is surrendered immediately upon transition while new livelihood income materializes with delay. Traditional livelihoods' share in economy is the structural indicator of the resilience base, not a residual. The Infrastructure and Resource Sector (Enabling infrastructure, Education and Awareness, Resource adequacy, Demand on resources, Resource limit) encodes information's dual role: the same node amplifies opportunity through R3 and risk perception through B6, a polarity reversal that is a canonical source of counterintuitive behavior (Sterman, 2000, p. 150). The Hazard and Fragility Sector (Hazard impacts, Exposure to new hazards on new livelihoods, Recovery potential after disaster) is the most structurally novel component: hazard exposure is endogenized, and Recovery potential declines as traditional livelihood share falls, a structural regime shift invisible until a shock activates the latent vulnerability.

Loop Architecture

The CLD contains five reinforcing loops (R1–R5) and six primary balancing loops (B1–B6), with B7 identified in the cross-validation case, organized into three behavioral regimes: growth amplification (R1–R5), hidden constraint accumulation (B1, B2a, B2b), and collapse dynamics (B3–B7). The five reinforcing loops operate at distinct timescales, R1 through social comparison and aspiration escalation (months); R2 through physical capital accumulation (years, subject to pipeline delays); R3 through information diffusion (medium timescale); R4 through income trajectory momentum, sensitive to the derivative of income rather than its level; R5 through cultural normalization (intergenerational, most persistent and most difficult to reverse), and this timescale differential is the structural mechanism behind the Pre-Loading Mandate in Section 6. The balancing loops engage at different thresholds: B1 and B5 are Limits to Growth structures activating as adoption approaches physical or market capacity; B2a and B2b are cash-flow constraints active throughout the transition period; B3 and B4 are hazard-mediated loops latent under normal conditions but dominant following a shock; B6 transforms information from accelerant to moderating force when institutional conditions permit. As demonstrated in the cross-validation, the

archetype is a structural template whose loop polarities can be conditionally inverted by context-specific configurations, a property that constitutes one of the paper's four theoretical contributions.

Growth Amplification Regime (R1–R5)

R1 Aspirational Contagion: Rising income generates visible peer success, elevating the income target, widening the aspiration gap ratio, deepening perceived failure, amplifying transition pressure, raising risk-taking appetite, and driving new livelihood entry, a reinforcing loop where the goal is endogenous to observed success (Duesenberry, 1949; Sterman, 2000). A critical delay operates between income rise and aspiration rise: the widening gap, not income level, is the proximate driver of transition pressure (Sterman, 1989). Aspiration gap drives behavior through an inverted-U motivational relationship: moderate gaps maximize motivation while large gaps produce demotivation and learned helplessness (Genicot and Ray, 2017, Proposition 2; Locke and Latham, 1990; Seligman, 1972), the structural switch documented in Table 5-1 that converts R1's growth dynamics into B3's collapse dynamics as the gap widens beyond the motivating range. R1 is an aspiration-matching engine: its direction is determined by which livelihood occupies the role of visible success in a given context, a property that becomes structurally consequential in the cross-validation.

R2 Infrastructure Investment: Rising household income funds enabling infrastructure irrigation in Nepal, energy installations in Myanmar, which raises resource adequacy and sustains new livelihood participation. The loop operates through two sequential delays (construction time and commissioning time), making R2 the archetype's dominant growth driver whose gain grows with adoption scale in ways that aspiration-chain loops, bounded by behavioral saturation, cannot match (Lyneis and Ford, 2007). Investment decisions made under favorable conditions continue arriving after conditions have changed, in Nepal, irrigation initiated in response to early vegetable profitability arrives two to four seasons later, by which point market saturation may have eroded margins.

Climate events do not only destroy productive capacity directly, they simultaneously damage functional infrastructure, extending commissioning delays and tightening the Latency Matching constraint precisely when the aspiration ratchet has locked transition pressure at its peak. This hazard-infrastructure interaction makes Energy-Limited systems like Myanmar especially vulnerable: infrastructure damage arrives as a discrete shock to the exact pipeline that the system depends on for its dominant growth mechanism.

R3 Information Access and Structural Ambiguity: Rising income funds access to information infrastructure that amplifies awareness of new livelihood opportunities, making R3 self-reinforcing in Myanmar where phone penetration directly reveals urban wages and accelerates secondary vocation entry (Low, 2023). In Nepal, the same information access node simultaneously feeds B6, R3 and B6 share an identical node but point in opposite directions, a structural ambiguity (Sterman, 2000, p. 150) meaning net effect depends entirely on program content design. Models omitting B6 while retaining R3 will systematically overestimate vegetable transition speed and durability.

R4 Income Trajectory: Households respond not only to current income level but to its perceived trajectory, what they interpret as movement toward or away from success. A rising income trajectory strengthens aspiration toward the productive livelihood; a falling trajectory amplifies departure pressure through what becomes R4b, the collapse accelerator (Sterman, 2000, pp. 518–522; Kahneman, 2011). This sensitivity to the derivative of income rather than its level produces asymmetric momentum dynamics: early success amplifies commitment, while early decline amplifies exit, driving sharp threshold behavior once the trajectory reverses.

R5 Cultural Normalization: As new livelihoods spread, they become culturally normalized, transformed from deliberate choices into default expectations reproduced through socialization rather than deliberate optimization (Bourdieu, 1986). Younger generations do not perceive themselves as transitioning; they perceive themselves as following the standard path. R5 is the most difficult loop to reverse on any policy-relevant timescale: once cultural

normalization has propagated through a generational cohort, income incentives alone cannot restore an alternative pathway.

Taken together, R1 through R5 constitute a layered reinforcing engine operating across timescales from months to generations. Their mutual amplification produces the rapid, path-dependent, and frequently irreversible livelihood transitions documented across the source cases, and their structural behavior under polarity inversion, demonstrated in the cross-validation, generates policy implications that are structurally opposite to those appropriate for the source cases, despite formally identical loop topology.

The Safe-Rate Bound

The structural dominance of R2 implies a design constraint. When the transition rate driven by R1 and R4 outpaces R2's infrastructure commissioning pipeline, demand exceeds supply, resource adequacy falls, and the system crosses into the collapse regime. The condition for stable scaling is:

$$r_{eff} \leq \frac{\theta - 1}{\tau}$$

where r_{eff} is the effective transition growth rate including aspiration amplification, τ is the infrastructure commissioning delay, and θ is the target capacity safety margin. Values of τ and θ are case-specific; the inequality form is general. This is not a recommendation to slow development, it is a structural constraint specifying when fast development becomes fragile development because the capacity of the system and market is not built at the same rate as the stress on the system.

Hidden Constraint Accumulation Regime (B1, B2a, B2b)

B1 Resource Constraint: Growing adoption increases demand on shared infrastructure while supply adjusts slowly, depressing Resource Adequacy and attenuating new livelihood entry rates, the Limits to Growth archetype (Senge, 1990; Sterman, 2000, Ch. 9) with two intervention points: expand supply or reduce the growth pressure driving demand. Nepal's irrigation deficit and Myanmar's energy ceiling are both supply-side bottlenecks, differing in the degree to which the constraint is graduated (Nepal) versus binary (Myanmar). The cross-validation reveals that B1 can invert to bind on the traditional rather than the new livelihood, an important structural property addressed in Part 2.

B2a Traditional Income Erosion Constraint: As households shift labor and land away from traditional activities, traditional income falls immediately, before new livelihood income has materialized. The declining household income base reduces the investable surplus available to fund further transition, attenuating the transition rate. This constraint is visible to households in real time and active throughout the transition period: the conversion season in Nepal, the period of reduced farming attention in Myanmar.

B2b New Livelihood Startup Cost Constraint: Entry into new livelihoods requires upfront capital, input costs for vegetable cultivation in Nepal, vocational training costs in Myanmar, that must be borne before new livelihood income materializes, creating a transient income valley that attenuates the transition rate at the moment of entry and moderates as the new livelihood matures.

B2a, B2b, and B3 all link traditional livelihood decline to constrained new livelihood entry, but through mechanistically distinct pathways whose policy implications diverge sharply. B2a and B2b are visible to households in real time. B3 is not.

Collapse Dynamics (B3–B7)

B3 The Fragility Trap (Traditional livelihoods → Traditional livelihoods' share in economy → Recovery potential after disaster → Hazard Impact on traditional livelihood → Household Income → New livelihoods): As traditional livelihood share erodes, Recovery potential declines silently while the system presents as succeeding, the Shifting the Burden archetype (Senge, 1990) in which household income gains mask the progressive depletion of the diversified base that absorbs hazard shocks (Walker et al., 2004; Folke, 2006). Counterintuitively, our analysis also found that diversification alone does not help increase or even maintain the mean income of the community per household, because the income gains from specialization are offset by the erosion of the resilience buffer that traditional livelihoods provided. Example: even with adaptive capacity eroding at 0.05/year under full specialization, resilience stock can have a half-life as low as approximately 14 years, more than half-depleted long after standard five-year program evaluation windows have closed and success has been declared. B3 is undetectable by any income indicator standard M&E frameworks track.

The aspiration-gap mechanism connects directly to B3's collapse dynamic through the motivational structure of R1. As the gap widens beyond the motivating range, the aspiration effect inverts from amplifying to dampening transition, the structural switch from positive to negative feedback documented in Table 5-1. This is the structural mechanism that converts the Delayed Reward Trap from a theory into a behavioral dynamic: as capacity constraints tighten, income falls, the gap widens, and the aspiration effect inverts, precisely when the system most needs household commitment to the new livelihood, it loses it.

Table 5-1: Aspiration Effect as a Function of the Normalized Aspiration Gap Ratio

Derived from expert-informed calibration consistent with Genicot and Ray (2017, Figure 2, Proposition 2), Atkinson (1957), Locke and Latham (1990), and Seligman (1972). Values verified against synthesis SFD (my.mdl). Motivating zone: $r \in (0, r^*)$ where $r^* \approx 0.75$ (upper unity-crossing of the LOOKUP; calibration-specific). These are structurally derived reference values requiring empirical validation before operational deployment. *

Aspiration Gap Ratio	-5.0	-2.0	-1.0	0	0.2	0.4	0.6	0.8	1	1.5	2	3	5	10
Effect	0.05 Base	0.1	0.3	1	1.35	1.55 Peak	1.3	0.9	0.5	0.3	0.2	0.1	0.05	0.01 Very disappointed

Above $r^* \approx 0.75$, the aspiration effect falls below 1.0 and transition pressure is dampened relative to neutral conditions. Above 1.0, households enter aspiration failure (Genicot and Ray, 2017, Proposition 2): effort collapses and reverse transition pressure accumulates.

B4 Vulnerability Amplification (New livelihoods → Exposure to new hazards on new livelihoods → Hazard impact on new livelihood → Household Income → New livelihoods): Dormant under no-hazard conditions, B4 activates abruptly when a shock occurs, translating aggregate exposure into income damage proportional to the vulnerability ratio of the new livelihood relative to the traditional one. In Nepal, vegetables carry almost three times the drought vulnerability of cereals (case-specific: 0.60 vs 0.30 as a conservative measure), the reinforcing loops generate their own fragility in proportion to their own success. In Myanmar, B4 inverts (case-specific: primary farming 1.00, secondary vocations 0.60; generic synthesis SFD defaults are 0.3 and 0.6) making transition structurally risk-reducing. This inversion affects the hazard damage calculation only, it does not affect the aspiration ratchet, which is governed separately by the MAX(0,...) operators in Social Aspiration Level and Perceived Income. Expanding participation in Nepal simultaneously narrows latitude (eroding the traditional buffer via B3) and increases precariousness (raising drought exposure via B4), a regime shift in Walker et al.'s (2004) formal sense; the system can remain functional across multiple drought-free periods, then cross a threshold abruptly when a sufficiently severe event activates both loops simultaneously.

B5 Market Saturation: Growing adoption increases aggregate supply, depressing prices and income per unit and slowing new entries. The saturation threshold is set by the exogenous Capacity Limit parameter but the feedback

operates continuously, each increment of adoption endogenously reduces income per unit through the Macro Capacity Effect lookup, producing the S-shaped saturation curves characteristic of technology adoption (Bass, 1969; Sterman, 2000, Ch. 9).

B6 Risk Education as Bifurcating Feedback (Education and Awareness → Risk assessment → Transition Pressure): Information is not a uniformly enabling input, it is a bifurcating variable whose net effect depends entirely on which downstream pathway dominates. The Information effect is $(1 + \text{Social Learning Effect}) \times (1 - \text{Risk Education Effect})$; at 30% B6 coverage and 50% adoption rate (New Livelihood Households = 500 of 1,000 total), Social Learning Effect = $0.3 \times 500/1000 = 0.15$ and Risk Education Effect = $0.09 \times 500/1000 = 0.045$, giving: $(1 + 0.15) \times (1 - 0.045) = 1.098$. B6 dampens but does not override R3 at this coverage level; at lower adoption rates the net Information effect will differ accordingly. Information infrastructure is not a policy instrument — it is a delivery mechanism whose effect depends entirely on content. Absent deliberate B6 activation, information programs default to R3 amplification by structural default, as in Myanmar. Nepal's ecological awareness curricula represent the only case in this study of deliberate B6 activation, measurably slowing cereal-land conversion.

B7 Livelihood Reversal: B7 was identified in the cross-validation and is not present in the source cases. When aspirations toward the productive livelihood turn positive, rather than negative as under transition pressure, a reverse flow activates, implying hysteresis in the weak sense: return is structurally possible but the path of return differs from the path of departure (Hirschman, 1970; Folke, 2006). Its absence in Nepal and Myanmar should be treated as a limiting condition rather than a universal property of the livelihood transition class. Full structural description is provided in Part 2.3.

Dominant Loop Finding and Its M&E Implication

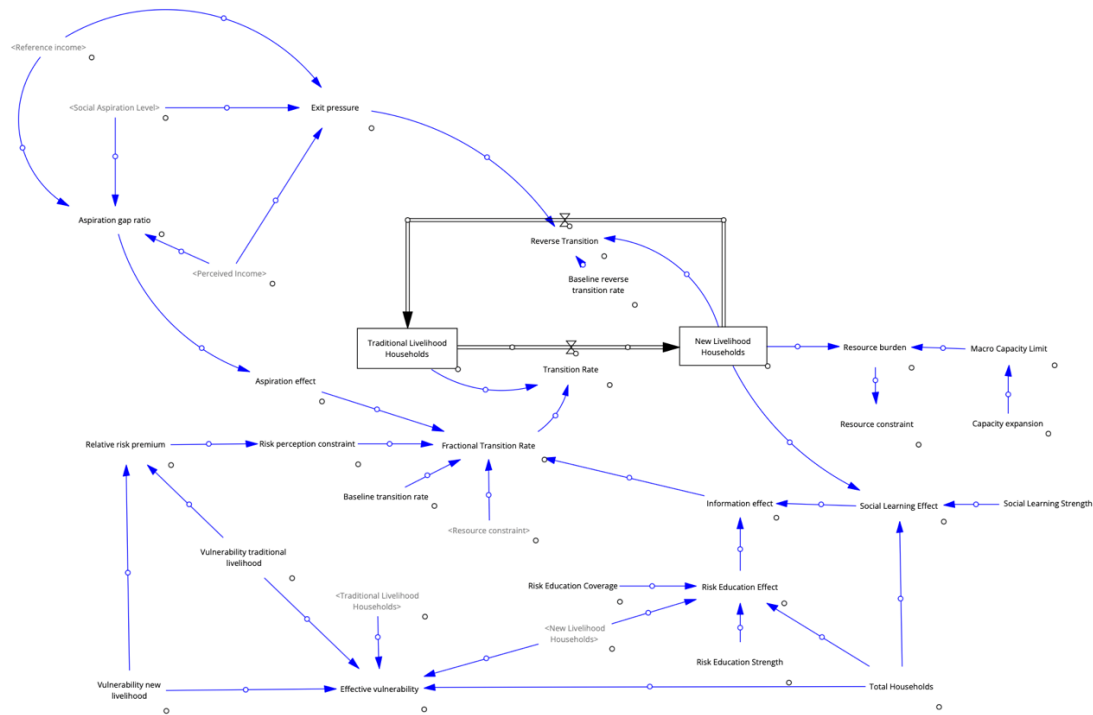
Existing M&E frameworks prioritize behavioral and attitudinal indicators corresponding to R1 and R4 (IPCC, 2022; World Bank, 2021). Structural analysis confirms R2 as dominant: its gain grows with adoption scale in ways that aspiration loops, bounded by behavioral saturation, cannot match. Frameworks monitoring aspiration and behavior but not infrastructure pipeline status will systematically misattribute both growth and collapse to the wrong structural drivers, declaring program success at precisely the moment when B3 is most deeply engaged and least visible in any income metric.

Part 1a: SFD Variable Inventory

SFD Variable Inventory and Theoretical Grounding

The stock-and-flow diagram (SFD) operationalizes the causal loop structure in four analytically distinct regions: the community region governing household livelihood states and climate exposure; the social aspiration region governing perceived income, aspirations, and transition propensity; the infrastructure region governing capital accumulation and productivity constraints; and the adaptive capacity region governing resilience erosion and recovery. All stock variables follow the fundamental accumulation identity (Forrester, 1961; Sterman, 2000, Eq. 6-1): $\text{Stock}(t) = \text{Stock}(t_0) + \int [\text{Inflow} - \text{Outflow}] dt$, creating system memory and path-dependence absent from purely algebraic formulations. The SFD comprises seven stocks and nine flows; complete formula derivations and theoretical citations are documented in Appendix A.

Region 1 — Community

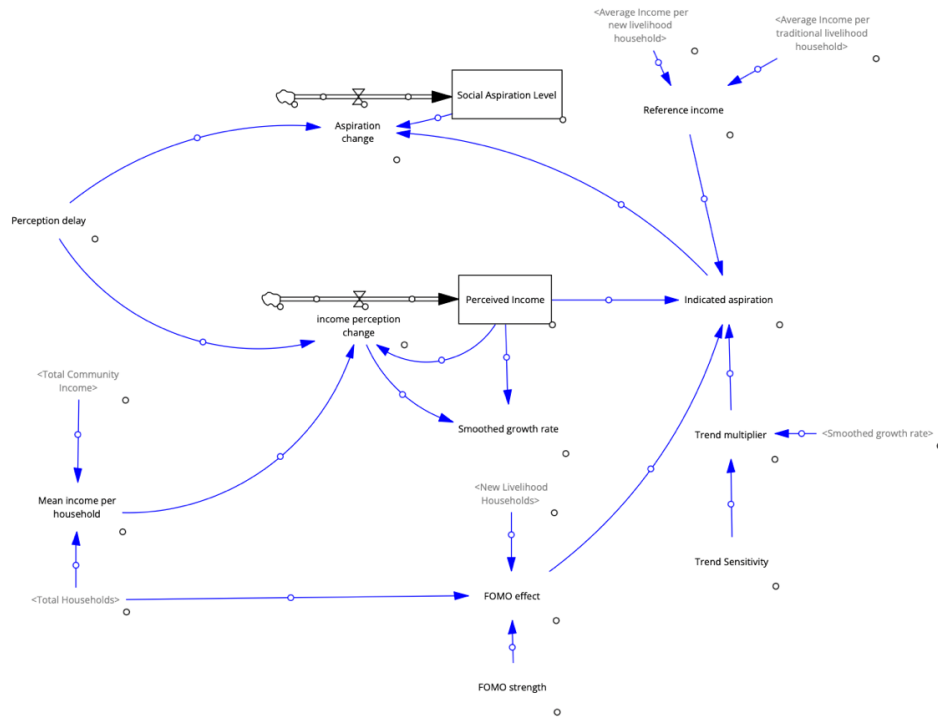


Two conserved population stocks — Traditional Livelihood Households (initial: 900) and New Livelihood Households (initial: 100, matching the synthesis model baseline) — partition a closed population of 1,000 households (Sterman, 2000, Ch. 12). The 90/10 split reflects Rogers' (1962) innovator/early-adopter phase (cumulative $\approx 16\%$). The stocks are coupled by $\text{Transition Rate} = \text{Traditional_HH} \times \text{Fractional_Transition_Rate}$ and $\text{Reverse Transition} = \text{New_HH} \times \text{Baseline_reverse_rate} (0.02/\text{year}) \times \text{Exit_pressure}$ — a population-times-propensity structure standard in diffusion modelling (Bass, 1969; Rogers, 1962). The lower baseline reverse rate (20% of the forward rate of 0.1/year) reflects switching costs and loss aversion: returning to traditional livelihoods is psychologically coded as admitting failure (Kahneman and Tversky, 1979; Hirschman, 1970). $\text{Exit pressure} = \text{MIN}(1, \text{MAX}(0, 1 - (\text{Perceived Income} / \text{Reference income}) / \text{Social Aspiration Level}))$ activates when income falls below the aspiration-weighted acceptable minimum, following Genicot and Ray (2017, Proposition 1) on aspiration failure thresholds.

Household income is computed separately for each livelihood type: $\text{Average Income per new livelihood household} = \text{Base_new_income} (150,000 \text{ currency/HH/yr}) \times \text{infrastructure_productivity_effect} \times \text{Macro_capacity_effect} + \text{subsidies}$, and $\text{Average Income per traditional household} = \text{Base_traditional_income} (67,000 \text{ currency/HH/yr}) \times \text{Traditional_productivity_effect}$. The multiplicative interaction of productivity and market-saturation terms is justified by Liebig's Law of the Minimum as applied to multi-limit growth systems (Sterman, 2000, pp. 348–351): if any single factor reaches zero, income collapses regardless of others. Total Community Income nets gross income against climate damage and infrastructure investment expenditure.

Climate damage is driven by $\text{Climate event occurs} = \text{RANDOM POISSON}(0, 100, \text{Hazard_frequency} \times \text{TIME STEP}, 0, 1, \text{seed})$, directly implementing a Poisson process ($\lambda = 0.3 \text{ events/year}$) in discrete time, consistent with the Herrera de León and Kopainsky (2019) framework for rare-event modelling in agricultural systems; the mean parameter $\text{Hazard_frequency} \times \text{TIME STEP}$ scales the annual event rate to the simulation evaluation interval. Infrastructure destruction applies the same denominator: $\text{infrastructure destruction} = \text{Climate event occurs} \times \text{Functional Infrastructure} \times \text{Infrastructure damage fraction} (0.2) / \text{TIME STEP}$, converting discrete fractional stock destruction into the instantaneous rate required by SD integration. Effective vulnerability is a population-weighted average of livelihood-specific vulnerability coefficients (new: 0.3; traditional: 0.6), reflecting empirical findings that subsistence livelihoods retain greater intrinsic climate buffering than commercialized alternatives (Gallopín, 2006; IPCC, 2022).

Region 2 — Social Aspiration



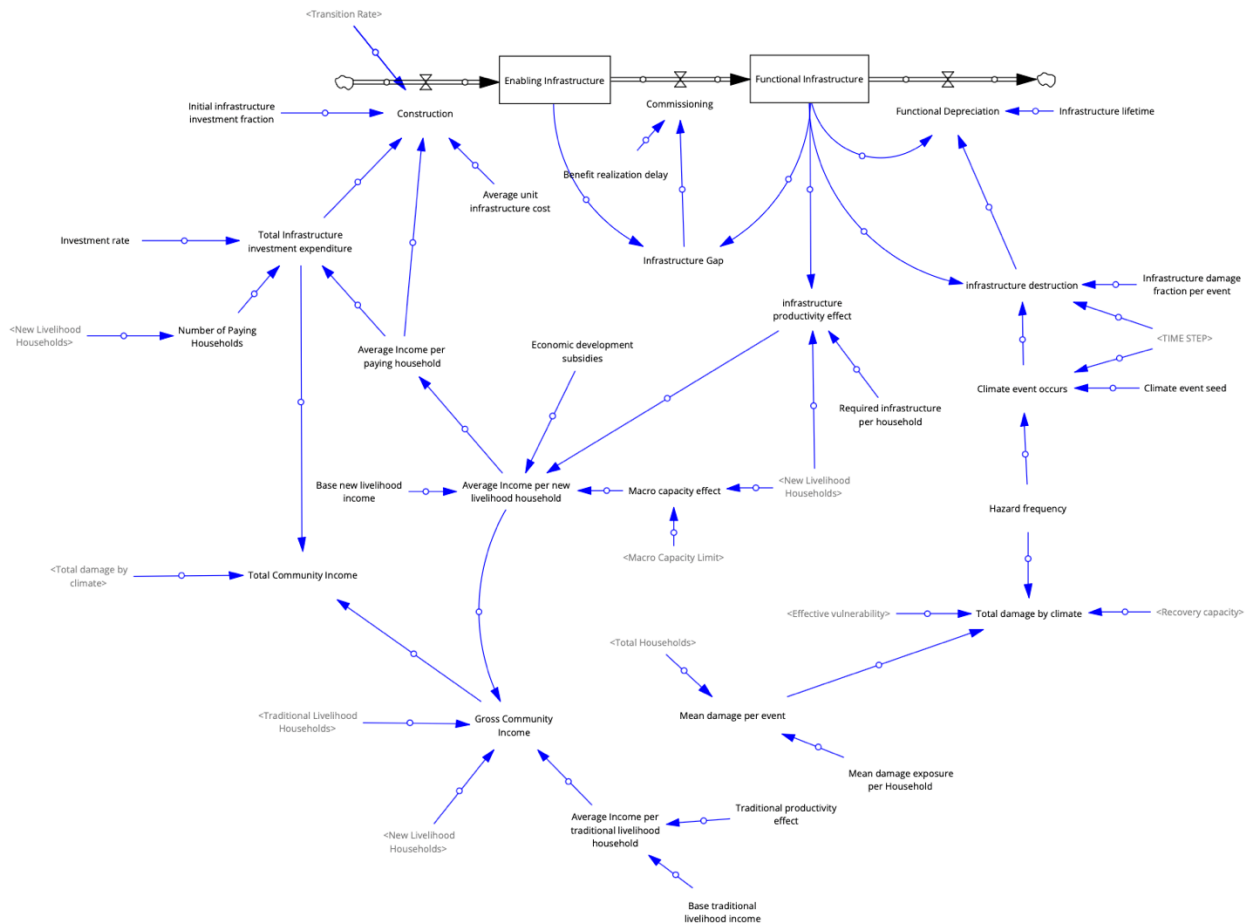
This region constitutes the behavioral core of the Delayed Reward Trap archetype. Perceived Income accumulates via $\text{income_perception_change} = \text{MAX}(0, (\text{Mean_income} - \text{Perceived}) / \text{Perception_delay})$, implementing a first-order information delay (Sterman, 2000, Eq. 16-1; perception delay: 0.25 years, reflecting quarterly information diffusion in semi-remote rural settings) with an asymmetric ratchet enforced by $\text{MAX}(0, \cdot)$: perception rises when actual income exceeds it but is frozen when income falls. This ratchet formalizes the Duesenberry (1949) reference-standard hypothesis — consumption norms adjust upward readily but resist downward revision — empirically supported by Bernard and Taffesse (2014), who document that aspirations in Ethiopian rural panels decline by less than five percentage points following a thirty-percent income shock. Kahneman and Tversky (1979) provide the loss-aversion mechanism: downward reference-point revision is weighted approximately 2.25× more costly than the equivalent upward gain.

Social Aspiration Level accumulates via $\text{Aspiration_change} = \text{MAX}(0, \text{Indicated_aspiration} - \text{Social_Aspiration_Level}) / \text{Perception_delay}$ — the identical ratchet structure enforcing Genicot and Ray's (2017, Eq. 1) history-dependent aspiration formation: aspirations cannot fall below the peak level previously reached. Indicated aspiration = $(\text{Perceived_Income} / \text{Reference_income}) \times \text{Trend_multiplier} \times (1 + \text{FOMO_effect})$ integrates three drivers: relative income position (Duesenberry, 1949; Easterlin, 1974), trend extrapolation (Sterman, 2000, pp. 609–611), and social comparison amplified by adoption proportion — the FOMO term, grounded in Frank (1985) and Genicot and Ray (2017). Reference income = $1.15 \times \text{MAX}(\text{Average new livelihood income}, \text{Average traditional livelihood income})$ sets a dynamic benchmark 15% above the better livelihood option.

The Fractional Transition Rate = $\text{Baseline_rate} \times \text{Aspiration_effect} \times \text{Information_effect} \times \text{Resource_constraint} \times \text{Risk_perception_constraint}$ takes a multiplicative form so that any single factor can shut down transitions entirely (Sterman, 2000, pp. 349–351). Aspiration_effect is a non-monotone lookup over the aspiration-gap ratio ($\text{gap} = \text{Social_Aspiration} - \text{Perceived/Reference}$), peaking at 1.55 when $\text{gap} \approx 0.4$ (challenging but achievable stretch goal, per Locke and Latham, 1990) and declining sharply beyond $\text{gap} \approx 0.75$, directly implementing the inverted-U investment-gap relationship of Genicot and Ray (2017, Figure 2, Proposition 2) and Atkinson's (1957) achievement-motivation theory; at $\text{gap} > 1.0$ households enter aspiration failure, and at extreme gaps learned

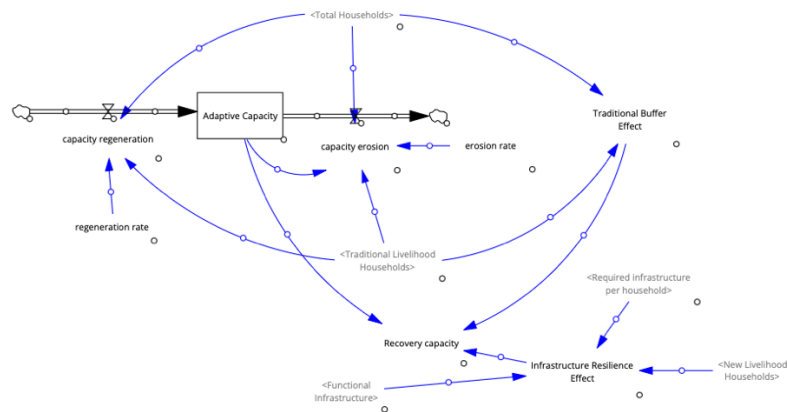
helplessness sets in (Seligman, 1972). $\text{Information_effect} = (1 + \text{Social_Learning_Effect}) \times (1 - \text{Risk_Education_Effect})$ combines Bandura's (1977) observational learning mechanism with a risk-communication dampener (at 30% B6 coverage and 50% adoption, the net effect is 1.098, B6 dampens but does not override R3; the value is adoption-rate dependent). Resource_constraint and Risk_perception_constraint are non-linear lookup tables capturing market saturation and perceived dread risk respectively (Slovic, 1987).

Region 3 — Infrastructure



Infrastructure accumulates through a second-order pipeline delay: investment expenditure funds Construction (capacity units entering the enabling pipeline), and Commissioning drains Enabling Infrastructure into Functional Infrastructure with a two-year benefit-realization delay (Benefit realization delay = 2 years), driven by Infrastructure Gap = Enabling – Functional. This two-stage structure produces completion-time distributions more realistic than the exponential distribution implied by first-order formulations (Sterman, 2000, pp. 422–424; Lyneis and Ford, 2007), while the gap-driven commissioning creates an endogenous catch-up dynamic. Functional Depreciation = Functional Infrastructure / Infrastructure_lifetime (10-year average lifetime, consistent with Sterman, 2000, Eq. 10-2) plus discrete event-driven destruction, representing the independent mechanisms of gradual wear-and-tear and sudden climate shock. Macro Capacity Limit is not a static ceiling but expands dynamically as $\text{Macro Capacity Limit} = 500 + \text{DELAY3}(300, 1.33)$, reflecting lagged market development through a third-order delay that partially relaxes the saturation constraint over the simulation horizon. The resulting Macro_capacity_effect lookup, declining from 1.0 at zero utilization to 0.5 at full capacity and 0.2 at 50% over-capacity, implements accelerating market saturation dynamics consistent with Cournot competition and logistic carrying-capacity models (Sterman, 2000, pp. 342–351). $\text{infrastructure_productivity_effect} = \text{MIN}(1, (\text{Functional Infrastructure} / \text{MAX}(1, \text{New Livelihood Households})) / \text{Required infrastructure per household})$ implements the intensive-form production relationship (Solow, 1956): productivity is proportional to capital per worker up to full adequacy, then flat, reflecting diminishing returns to additional infrastructure beyond requirements.

Region 4 — Adaptive Capacity



Adaptive Capacity accumulates as $\text{INTEG}(\text{capacity_regeneration} - \text{capacity_erosion}, 1.0)$, where $\text{capacity_erosion} = \text{erosion_rate} (0.05/\text{yr}) \times (1 - \text{Traditional_HH}/\text{Total_HH}) \times \text{Adaptive_Capacity}$ and $\text{capacity_regeneration} = \text{regeneration_rate} (0.02/\text{yr}) \times (\text{Traditional_HH}/\text{Total_HH})$. The proportional-to-specialization erosion term formalizes Berkes and Turner's (2006) finding that traditional ecological knowledge erodes in proportion to the abandonment of associated practices, while the proportional-to-stock structure produces a half-life of approximately 14 years under full specialisation. The lower regeneration rate (40% of the erosion rate) reflects the empirically documented asymmetry between knowledge loss and revival (Folke et al., 2010): easier to lose than rebuild. Recovery capacity = $\text{Adaptive_Capacity} \times \text{Infrastructure_Resilience_Effect} \times \text{Traditional_Buffer_Effect}$ combines three independently justified resilience components, institutional adaptive capacity (Walker et al., 2004), infrastructure adequacy, and the traditional-livelihood buffer ($\text{Traditional_Buffer} = 0.2 + 0.8 \times \text{Traditional_HH}/\text{Total_HH}$, preserving a floor of 0.2 at full specialisation) — as a multiplicative product, consistent with the principle that resilience failure is determined by its most constraining dimension (Meadows et al., 1972). Recovery capacity scales the denominator of the climate-damage term, so that declining adaptive capacity amplifies damage non-linearly, implementing the coupled social-ecological vulnerability feedback of Gallopín (2006): B3 is not merely a structural description but a calculable dynamic relationship in which the same hazard event produces progressively larger income damage as the traditional livelihood base erodes.

Part 2: Cross-Case Application

Methodological Framing

The archetype in Part 1 was derived inductively from Nepal and Myanmar through the Grounded Theory synthesis described in Section 3. Both cases share a structural core — aspiration-driven transition, infrastructure pipeline delay, latent fragility accumulation — but diverge sharply in binding constraint type and B4 polarity. This combination of structural similarity and contextual difference provided the empirical foundation for abstracting a generalizable feedback topology and building the synthesis SFD.

Bhutan was then selected as the cross-validation case precisely because its surface structure diverges most sharply from the source cases. Where Nepal and Myanmar document households aspiring toward a new and economically superior livelihood, Bhutan documents households departing from a productive traditional one under aspirational pressure toward an urban alternative. The cross-validation question was specific: can the same loop topology, through polarity inversion alone and without structural modification, account for Bhutan's behavioral dynamics? Section 2.3 answers this question. Section 2.4 draws on all three cases to establish what is structurally universal, what is context-contingent, and what is conditionally invertible.

Following Richardson and Pugh (1981), validation proceeds through progressive structural testing: the same feedback topology held fixed while boundary conditions, parameter magnitudes, and polarity assignments vary across cases.

Part 2.1 Nepal — Source Case 1: Resource-Limited Transition System

Nepal contributed the core structural skeleton of the archetype: R1, R2, B3, B4, and the principle that balancing constraints can be endogenously self-intensifying. The critical B1 contribution is the polarity inversion — Wildlife Intrusion = 8 / Vegetable Production — meaning expanding adoption actively tightens the constraint rather than simply encountering a fixed ceiling, a structural property absent from standard carrying capacity representations. Loops R1 and R5 provide the primary adoption engine, confirmed by reference mode data: vegetable production rose from 12,183 to 16,055 metric tons from 2010/11 to 2015/16 while cereal land area declined systematically. B4 is strongly active with case-specific vulnerability coefficients (vegetables 0.60, cereals 0.30), meaning the reinforcing loops generate their own fragility in proportion to their own success, while B3 closes the argument: as cereal land contracts, there is no fallback when drought strikes. Nepal also established B6 as empirically activatable through deliberate program design, the only such case in this study, demonstrating that B4 and B6 attack vulnerability through different causal pathways: B4 penalizes exposure after the fact; B6 tempers aspiration before it translates into irreversible land conversion.

Part 2.2 Myanmar — Source Case 2: Energy-Limited Transition System

Myanmar confirmed the archetype's generalizability beyond agricultural land transitions and contributed three structural features absent from Nepal: a binding infrastructure constraint that is binary rather than graduated; a B4 polarity inversion establishing vulnerability amplification as context-directional rather than universal; and a B3 fragility mechanism operating through market exposure dependency rather than ecological knowledge erosion. The dominant structural correspondence is between the archetype's Enabling Infrastructure and Myanmar's energy supply, collapsing from multiple substitutable inputs to a single variable whose absence is binary in operational effect, making R2 acutely sensitive: when functional energy infrastructure is absent, R2 cannot close regardless of income or aspiration levels. B4 inverts relative to Nepal (primary farming 1.00, secondary vocations 0.60; case-specific), making transition structurally risk-reducing, the same loop that amplifies fragility in Nepal reduces it in Myanmar, establishing B4 polarity as the paper's second theoretical contribution. The dominant brakes on adoption are B2a and B1, not vulnerability exposure. When the energy ceiling is hit, energy shortage drives firewood collection, displacing productive hours, collapsing income, and preventing energy investment, while the aspiration ratchet simultaneously locks aspirations at the peak reached during R1 amplification, pushing the system into the demotivating zone of Table 5-1. Standard M&E reads this as a simple income downturn. It is a structural energy-aspiration feedback trap

Part 2.3 Bhutan — Cross-Validation: Aspiration-Limited Transition System (Structural Inversion)

With the archetype derived from Nepal and Myanmar, Bhutan was selected as the cross-validation case. The question was specific: can the same feedback topology, through polarity inversion alone and without structural modification, account for a system in which the productive livelihood is traditional, the dominant driver is cultural departure rather than economic aspiration toward a superior alternative, and transition exhibits bidirectional properties absent from the source cases?

Context and Livelihood Shift

Yak herding communities in Haa district, representative of highland pastoral systems across 11 of Bhutan's 20 dzongkhags, sustain approximately 39,500 yaks through a diversified product system of milk, butter, cheese, wool,

and transport that has anchored high-altitude livelihoods for generations. Herding is transhumant by nature, requiring seasonal movement between summer and winter pastures, making labor availability and pastureland quality simultaneously necessary inputs. A sustained decline in herd populations and herding households has been documented in recent decades (Wangdi, 2016), driven not primarily by climate stress but by a generational aspirational shift: younger community members increasingly perceive yak rearing as physically arduous and economically inferior to urban wage labor, civil service, and trade.

Household income flows through the yak value chain: herd productivity generates milk and raw materials processed into tradeable products. Scenario analysis confirmed aspiration change as the dominant system driver, the Aspiration Change scenario produces potential collapse while the Hazard Only scenario, an identical regeneration rate shock with zero aspiration change, shows decline followed by self-organization and recovery. As youth migrate, Labor Availability declines, constraining herd management, degrading pasture through reduced rotational management, depressing Milk Processing Capacity and Income of Yak Herders, further widening the income differential and completing the reinforcing departure cycle. The COVID-19 reverse migration episode reveals the recovery asymmetry embedded in this structure: the rate of household return to yak rearing is significantly faster than the recovery of yak product revenue, producing a period of low income that risks triggering secondary out-migration before the system stabilizes.

Applying the Archetype

The cross-validation confirmed the archetype's structural template holds, but with every major loop polarity inverted. In Nepal and Myanmar, "New livelihoods" is the economically superior productive aspiration; in Bhutan it maps to Urban Employment, aspirational attractive but structurally fragile. "Traditional livelihoods" maps not to a declining subsistence base but to Yak Rearing, the economically superior, ecologically productive system being abandoned.

Archetype Variable or Loop	Nepal / Myanmar	Bhutan
New livelihoods	Vegetables / Secondary vocations: the economically superior destination being adopted	Urban employment: aspirationally attractive but economically fragile and ecologically disconnected
Traditional livelihoods	Cereal / Primary farming: the declining base being abandoned	Yak rearing: the economically superior, ecologically embedded system being depleted
R1	Drives adoption of the new livelihood as peer success becomes visible	Drives departure from the traditional livelihood as herding income falls below urban alternatives
R2	Builds infrastructure for the new livelihood (irrigation, energy grid)	Maintains infrastructure for the traditional livelihood (milk processing, cold chain, market roads)
B3	Acts as a damping mechanism: residual traditional income provides a partial shock buffer	Acts as the dominant collapse driver: eroding recovery potential accelerates the departure spiral
Enabling infrastructure	Irrigation canals / energy grid	Milk processing capacity, cold chain, market roads
Investment logic	Driven by New Livelihood Household income	Driven by Traditional Livelihood Household income: structurally inverted
Social Aspiration	Rises as new livelihood income becomes visible to peers	Falls as herding income declines relative to urban alternatives; urban aspiration fills the gap

Three structural inversions defined the cross-validation finding. First, R2 and B1 bind on the traditional livelihood: pastureland sustains yak herding, so R2 reinforces herding when healthy and collapses when pasture degrades; B1 operates as a push factor out of herding rather than a brake on new-livelihood adoption. Second, R1 inverts: yak income reinforces herding aspiration; when income declines, R1 reverses sign and amplifies exit, the same loop

that retained youths in herding begins accelerating their departure. Third, the direction of transition inverts: Nepal and Myanmar are pulled by new-livelihood attractiveness; Bhutan is pushed by traditional livelihood failure, with urban employment absorbing displaced youths as a residual destination. This bidirectional aspiration gate, unique to Bhutan and absent from Nepal and Myanmar, is the structural basis for B7: when herding aspirations turn positive, a reverse flow activates and return migration becomes structurally possible, though the path of return differs from the path of departure (Hirschman, 1970; Folke, 2006).

B3, a damping mechanism in Nepal and Myanmar, is in Bhutan the dominant collapse driver. As yak rearing declines, Traditional Livelihoods' Share falls, Recovery Potential erodes, Hazard Impact on the traditional livelihood grows, Household Income is damaged, the income differential widens, urban aspiration amplifies through R1, and departure accelerates. The aspiration ratchet holds aspirations at their peak level while herding income falls, pushing the system into the demotivating zone of Table 5-1 precisely when return to herding would be structurally beneficial. Collapse shows peak departure on the order of several dozen youths per year under the combined aspiration-and-hazard scenario. Recovery requires clearing two sequential bottlenecks: the social bottleneck requiring a sufficiently positive income trend signal to trigger return migration, and the ecological bottleneck with pasture regeneration operating on a decadal timescale. The COVID-19 reverse migration of 2020–2021 demonstrates the social bottleneck can be overcome by income shock; the ecological restoration requirement remains a structural delay that no aspiration signal alone can accelerate. Once past the tipping threshold, this process may be effectively irreversible on planning-relevant timescales.

The cross-validation was successful: no structural modification to the archetype was required. Bhutan's dynamics are fully accounted for by the existing topology under polarity inversion, confirming that the archetype is genuinely generative rather than a post-hoc description of two similar systems.

2.4 Cross-Case Synthesis: Structure, Dominance, and Polarity

The synthesis across two source cases and one cross-validation establishes three properties of the archetype that no single case could establish alone. Structural robustness. The same feedback skeleton is identifiably present across Nepal's agricultural land transition, Myanmar's energy-constrained secondary vocation economy, and Bhutan's pastoral herding system. All reinforcing and balancing loops are present in each case; what varies is parameterization, dominant coalition, and polarity assignment. No additional loops were required to account for any case.

Behavioral contingency. Dominant loop structure shifts across cases in ways that produce qualitatively opposite policy implications from structurally identical interventions. In Nepal, R1–R2–R5 dominates early dynamics; dominance shifts toward B4 as vulnerability accumulates and B3 as the traditional buffer disappears. In Myanmar, the same coalition dominates but B4's inverted polarity means the dominance shift toward balancing loops does not generate fragility — B1 provides the primary brake, and the aspiration ratchet drives the collapse mechanism independently of B4. In Bhutan, neither reinforcing coalition dominates in the conventional direction; degradation of traditional livelihood infrastructure destabilizes R1 and R2 from below, producing a collapse-driven transition governed by the R4 income trajectory signal, with B3 as the dominant collapse driver rather than the damping mechanism it constitutes in Nepal and Myanmar. Conditional polarity reversal as a theoretical property. The Bhutan cross-validation established that the same loop can operate in opposite directions under context-specific configurations without requiring a different model. This property, absent from canonical SD archetypes such as *Fixes That Fail* or *Limits to Growth*, both of which are context-invariant, is what gives the *Delayed Reward Trap* its comparative analytical power across structurally diverse empirical contexts. It is also what makes the archetype genuinely dangerous to misuse: an intervention derived from the Nepal or Myanmar instantiation, applied to a Bhutan-type system without polarity diagnosis, will produce outcomes structurally opposite to those intended. Archetype-based reasoning accelerates problem framing, the same structural vocabulary applies across all three cases. But it does not substitute for the polarity diagnosis and dominant loop identification that each context requires before any intervention logic can be responsibly applied.

6. From Structural Diagnosis to Structural Prescription: Design Principles and M&E Framework

The archetype developed in Section 5 is a diagnostic instrument. But diagnosis without prescription is incomplete. The feedback logic of the Delayed Reward Trap does not merely describe how systems fail, it specifies the structural conditions under which they would not.

Part A: Three Design Principles

Design Principle 1: Latency Matching

The effective rate of livelihood transition must not exceed the rate at which enabling infrastructure can be commissioned into functional capacity.

Formally,

$$r_{eff} \leq \frac{\theta - 1}{\tau}$$

where r_{eff} is the effective transition growth rate including aspiration amplification, τ is the infrastructure commissioning delay, and θ is the target capacity safety margin. When $r_{eff} \times \tau > (\theta - 1)$, the transition rate outpaces the R2 pipeline and the system crosses into the collapse regime. Myanmar's energy ceiling creates near-zero τ tolerance; Nepal's irrigation lag creates a softer version of the same dynamic; Bhutan's pasture regeneration ($\tau \approx 10$ years) means the safe rate of herding departure is structurally very low. Values of τ and θ are case-specific; the inequality form is general.

Testable hypothesis: Programs where $r_{eff} \times \tau > (\theta - 1)$, at any point will exhibit higher reverse transition rates, greater income volatility, and lower long-run adoption than programs satisfying the inequality throughout.

Operationalization: Estimate τ for the binding infrastructure type before program design. The ratio $(\theta - 1)/\tau$ gives the maximum safe transition rate. Program incentive structures should not stimulate adoption beyond this bound.

Design Principle 2: Pre-Loading

Functional infrastructure capacity must be established as a stock before aspirations are triggered as a flow. R1 responds to observable peer income in months; R2 accumulates physical capital over years. When aspiration amplification is triggered before functional infrastructure exists, the reinforcing engine fires at full gain while the dominant enabler is still in the pipeline — the structural recipe for overshoot. Once triggered, aspirations are not revocable: the ratchet properties of perceived income and social aspiration ensure they do not fall when income disappointment arrives. Standard development programs trigger aspirations first — demonstration farms, income comparison workshops, awareness campaigns — and fund infrastructure concurrently or in response to uptake. The structural analysis of R2 shows this to be precisely backwards.

Testable hypothesis: Programs investing in functional infrastructure prior to aspiration-triggering activities will show lower gap widening, lower reverse transition rates, and higher long-run adoption than programs running infrastructure investment concurrently with social mobilization.

Operationalization: Program logic models should include an explicit infrastructure readiness gate, a measurable threshold of functional capacity per anticipated household, that must be crossed before aspiration-triggering activities begin.

Design Principle 3: Shadow Cost of Resilience Accounting

Every livelihood transition program imposes a shadow cost, the erosion of adaptive capacity and traditional livelihood buffer, not captured in standard cost-benefit analysis. B3 operates silently during apparent program success. Recovery potential erodes with no contemporaneous income signal; when a hazard event occurs, the eroded buffer converts a manageable income shortfall into a catastrophic shock. This cost is calculable: erosion rate $\times$ proportion specializing $\times$ current capacity $\times$ expected hazard damage per unit of lost recovery potential gives a shadow cost in currency units per year, directly comparable against program income benefits.

Testable hypothesis: Programs incorporating shadow cost accounting and funding adaptive capacity maintenance will show lower peak-to-trough income swings during hazard events and higher household welfare over ten-year post-transition horizons.

Operationalization: Program appraisal documents should include a Resilience Shadow Cost section projecting capacity erosion under the proposed transition rate and pricing the maintenance required to hold adaptive capacity above 0.6 of initial capacity, the level below which non-linearity in the recovery capacity relationship accelerates damage sharply.

Part B: The M&E Framework

The Two Core Indicators

$$CSI = \frac{\min\left(\frac{\dot{C}}{C}, \frac{\dot{B}}{B}\right)}{\frac{\dot{A}}{A}}$$

where $\frac{\dot{C}}{C}$ is the proportional growth rate of functional infrastructure capacity, $\frac{\dot{B}}{B}$ is the proportional growth rate of adaptive capacity (proxied by traditional livelihood viability indicators), and $\frac{\dot{A}}{A}$ is the proportional growth rate of aspiration-driven adoption. The numerator takes the binding constraint in Liebig's Law sense. When $CSI = 1.0$, capacity and adoption are co-scaling. The structural reference threshold $CSI_{safe} \approx 0.8$, derived from the Latency Matching condition, signals that adoption outpaces capacity by more than 20%, a margin that consistently precedes collapse dynamics across the archetype's parameter range. CSI_{safe} must be recalculated using case-specific τ and θ . Programs should be flagged for structural review when CSI falls below CSI_{safe} for two consecutive monitoring cycles. **Gap = Initial Traditional Livelihood Income – Current Traditional Livelihood Income**; $Gap_{critical}$ corresponds to the income buffer level below which a single mean-magnitude hazard event drives the system into the collapse pathway. It is a function of λ , the new livelihood vulnerability coefficient, and baseline income levels — context-dependent and derived from case-specific parameterization. The qualitative collapse behavior is robust to $\pm 30\%$ variation in key income parameters. A Gap approaching $Gap_{critical}$ in Nepal ($\lambda \approx 0.3$ events/year) is considerably more dangerous than the same relative Gap in a system with $\lambda = 0.1$ events/year — the higher hazard frequency reduces the expected time before a triggering event.

The Three Pathways

Steady-State (Green): $CSI \geq CSI_{safe}$; $Gap < 0.6 \times Gap_{critical}$; reverse transition rate $< 5\%/year$; aspiration gap ratio $r \in (0, r^*)$, where r^* is the gap ratio at which $Aspiration_{effect}(r^*) = 1$; interpolating the calibrated LOOKUP, $r^* \approx 0.75$ for the current parameterization. The reinforcing engine is dominant. Quarterly monitoring; no structural intervention required.

Stress (Yellow): CSI between CSI_{warning} and CSI_{safe} for two consecutive quarters; Gap between $0.6 \times \text{Gap}_{\text{critical}}$ and Gap_{critical}; reverse transition rate 5–15%/year; aspiration gap ratio $r \in (r^*, 1.0)$, where $r^* \approx 0.75$ (calibration-specific interpolated value); the effect falls below unity at r^* and continues declining to 0.50 at gap 1.0). The specific indicator breached identifies which mechanism is activating: CSI → B1 tightening; Gap → B3 accumulating; reverse transitions → B2a and B2b or exit pressure rising; aspiration gap above 0.7 → demotivation zone. Monthly monitoring; activate pathway-specific intervention.

Collapse (Red): CSI < CSI_{warning}; Gap > Gap_{critical}; hazard event when Gap > $0.8 \times \text{Gap}_{\text{critical}}$; reverse transition rate > 15%/year; aspiration gap ratio > 1.0 (effect < 0.5). B3 is dominant and the fragility trap has activated. Immediate program review. Pair capacity investment with income stabilization subsidies. Do not increase aspiration triggers — above gap ratio 1.0, additional aspiration stimulation reduces motivation further. Programs designed to accelerate transitions should be paused; programs stabilizing traditional livelihoods should be activated.

Table 6-1: Five-Indicator Monitoring Dashboard

Indicator	What it measures	Frequency	Green	Yellow	Red
Co-Scaling Index (CSI)	Rate coupling: capacity growth vs adoption growth	Quarterly	$\geq \text{CSI}_{\text{safe}}$	$\text{CSI}_{\text{warning}} - \text{CSI}_{\text{safe}}$	$< \text{CSI}_{\text{warning}}$
r_{eff} vs r_{max}	Transition rate vs safe-rate bound $(\theta-1)/\tau$	Quarterly	$r_{\text{eff}} < 0.8 \times r_{\text{max}}$	$0.8 - 1.0 \times r_{\text{max}}$	$> r_{\text{max}}$
Gap Indicator	Income buffer erosion	Monthly	$< 0.6 \times \text{Gap}_{\text{critical}}$	$0.6 - 1.0 \times \text{Gap}_{\text{critical}}$	$> \text{Gap}_{\text{critical}}$
Aspiration Gap Ratio	Aspiration-income gap vs motivating range	Quarterly	$r \in (0, r^*)$, where r^* solves $\text{Aspiration}_{\text{effect}}(r^*) = 1$; $r^* \approx 0.75$ for current LOOKUP parameterization (effect > 1.0)	$r \in (r^*, 1.0)$; effect falls below unity at r^* and declines to 0.50 at gap 1.0	$r > 1.0$ (aspiration failure zone; effect < 0.5)
Adaptive Capacity Index	Traditional livelihood buffer viability	Quarterly	> 0.7	$0.5 - 0.7$	< 0.5

Note: CSI_{safe}, CSI_{warning}, and Gap_{critical} are structurally derived reference values requiring calculation from case-specific τ , θ , λ , and vulnerability parameters before deployment. Aspiration Gap Ratio thresholds are derived from Table 5-1 and require empirical validation. The motivating zone boundary r^ is the upper unity-crossing of the $\text{Aspiration}_{\text{effect}}$ LOOKUP, defined by: $r^* = \text{MIN}(-5, \text{Social Aspiration Level} - \text{Perceived Income} / \text{Reference income})$ such that $\text{Aspiration}_{\text{effect}}(r^*) = 1$. For the current model calibration, linear interpolation between the bracketing lookup points (0.6, 1.30) and (0.8, 0.90) gives $r^* = 0.6 + (1.0 - 1.30) / (0.90 - 1.30) \times 0.2 = 0.75$. This value is calibration-specific and will shift with any re-parameterization of the LOOKUP.*

Toward a Feedback-Informed Theory of Change

Standard ToC frameworks share three structural failure modes the archetype directly reveals: phase conflation (treating transition as a single event rather than a multi-phase process with distinct growth, stress, and collapse phases); loop invisibility (modeling only forward causal chains without feedback mechanisms, preventing testable predictions under stress); and threshold blindness (failing to specify conditions at which qualitative behavioral shifts occur). A feedback-informed ToC writes loop labels, delay estimates, and threshold conditions directly into the programme logic model — Latency Matching becomes a testable sequencing assumption, Pre-Loading Mandate becomes a program milestone gate, and Shadow Cost Accounting becomes a funded budget line. Each

assumption is testable, each has a monitoring indicator, and each has a decision rule specifying what program adjustment is triggered if the assumption is violated.

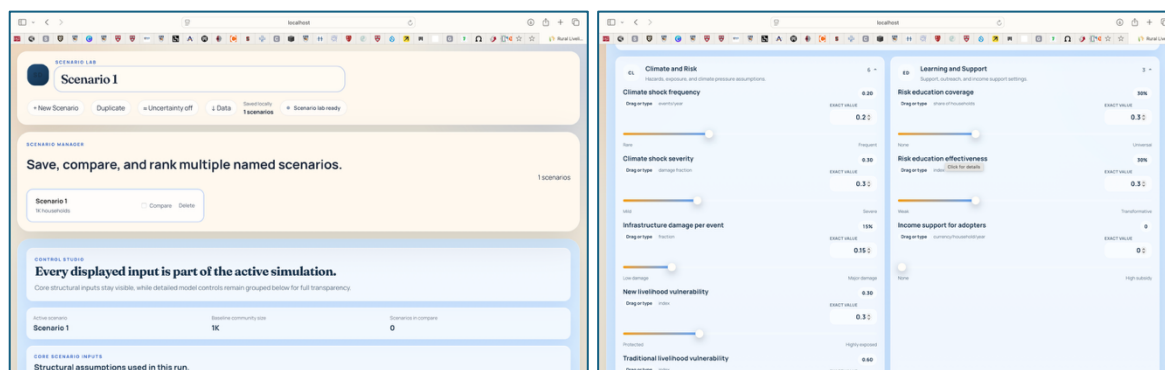
The Practitioner Tool: From Archetype to Interactive Policy Learning Environment

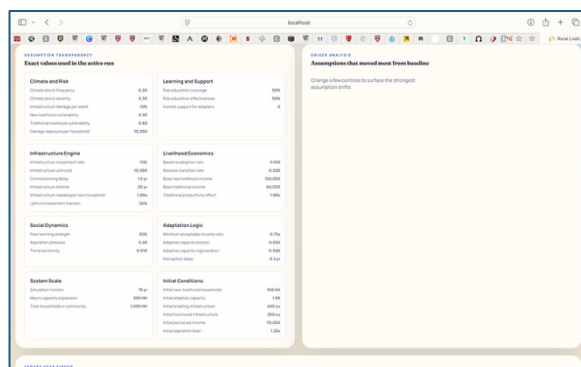
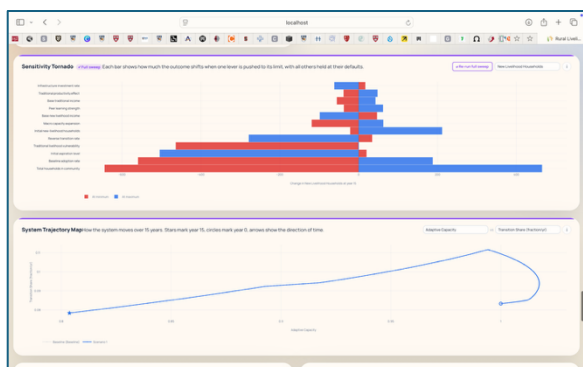
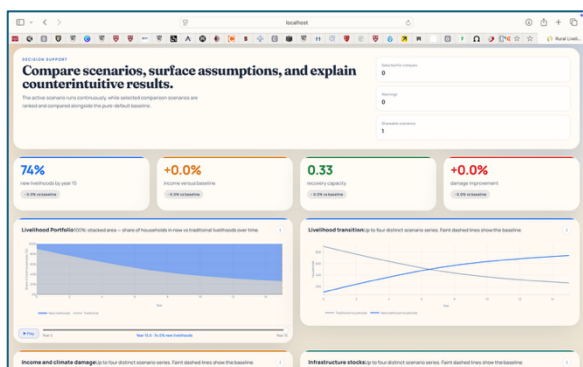
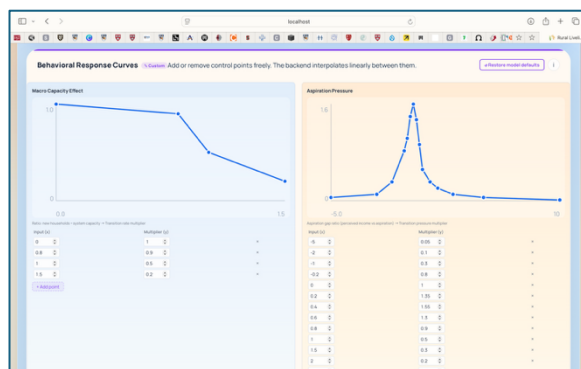
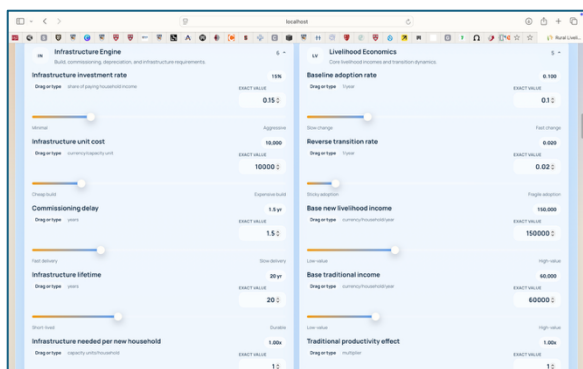
The structural findings of Sections 5 and 6 are delivered through an open interactive simulation tool built on the synthesis SFD and developed in active collaboration with ICIMOD program managers. Following the design philosophy of En-ROADS (Sterman et al., 2020), the tool allows M&E officers, program designers, and policy advisors to run scenario experiments directly against the archetype's feedback structure without any computational modeling background. Users adjust transition rate, infrastructure investment timing, hazard frequency, and vulnerability coefficients, and observe in real time how the Co-Scaling Index, Gap Indicator, and Adaptive Capacity Index respond. The tool makes the three design principles operational: Latency Matching appears as a visible constraint on the dashboard when $r_{\text{eff}} \times \tau$ exceeds the safe-rate bound; Pre-Loading appears as a sequencing gate that must be satisfied before aspiration-trigger scenarios are unlocked; and Shadow Cost appears as a running monetary estimate updating with each scenario run. The aim is to encourage Impact of Systems and complexity discourse on policy education while making feedback thinking legible and consequential to the practitioners who make the program decisions that determine whether transitions build or erode resilience.

Why This Matters for Systems and Complexity Discourse

The field has produced powerful conceptual tools, from resilience frameworks to causal loop archetypes, that remain largely confined to academic and consulting contexts because they demand modeling capacities that field practitioners do not have and program timelines do not allow. This tool is a direct attempt to close that gap: to take a formally grounded, cross-case validated SD archetype and render it in a form that an M&E officer in Kathmandu or Naypyidaw can run on a laptop during a program review meeting. The design lesson from En-ROADS, that accessibility and analytical rigor are not in tension if the structural work is done upstream, is the animating principle. The Delayed Reward Trap archetype does the structural work; the tool delivers it. We are currently working with ICIMOD to calibrate the tool to field monitoring data from all three cases, and to run practitioner validation workshops that will progressively ground the threshold parameters in operational experience. The tool is not context-locked to the HKH; it is applicable wherever aspiration-driven livelihood transitions govern adaptive capacity outcomes, which is to say, across a very wide class of development and climate adaptation programs globally.

A few pictures of the tool as of now





7. Discussion

7.1 Three Policy Dangers Revealed by the Archetype

The Fragility Trap Danger. When R2 and R1 jointly accelerate livelihood transition, household income rises and diversification rates improve — precisely the indicators standard development monitoring prioritizes (IPCC, 2022; World Bank, 2021). These are the wrong indicators for detecting B3. The mechanism driving B3 operates orthogonally to income measures: as households deepen commitment to new livelihoods, the skills, assets, and social networks sustaining traditional livelihoods atrophy silently. B3 is an eroding goal structure (Stermann, 2000, Ch. 8) — the goal of diversified income as resilience buffer produces no contemporaneous signal of its own erosion. Standard income monitoring cannot detect the trap until a hazard event activates it, at which point the damage is already structural. Income and diversification rate are lagging indicators of B3 dynamics; interventions accelerating R1 and R2 without monitoring recovery potential are not development successes — they are fragility investments operating on a delay.

The Information Bifurcation Danger. The same information infrastructure activates either R3 (opportunity awareness accelerating transition) or B6 (risk education dampening premature transitions), depending entirely on content and framing. In Myanmar, phone penetration activates R3 by diffusing income comparison signals; in Nepal, ecological awareness curricula activate B6, measurably slowing cereal-land conversion. Information infrastructure is not a policy instrument — it is a delivery mechanism. Absent deliberate B6 activation, information programs default to R3 amplification by structural default. The resolution lies in sequencing: R3 content is

appropriate during the pre-loading phase; B6 content is appropriate once infrastructure is functional and fragility accumulation begins.

The Context Transfer Danger. Structurally homologous loops produce opposite behavioral effects across contexts when key causal link polarities are inverted. Strengthening irrigation in Nepal accelerates vegetable adoption by relaxing B1 on the new livelihood; the analogous intervention in Bhutan — strengthening pastureland — relaxes B1 on the traditional livelihood, slowing urban migration. These are directional reversals, not differences of magnitude. A policy claim that "livelihood diversification reduces vulnerability" is empirically correct in Myanmar and potentially harmful in Nepal. Before any policy validated in one context is extended to another, the dominant loop structure, causal link polarities, and current system state of the receiving context must be explicitly characterized.

7.2 Leverage Points

Following Meadows (1999) and Sterman (2000), three intervention tiers correspond to increasing structural depth. *Parameter interventions*, adjusting rates, delays, or constants, are necessary but low leverage: accelerating infrastructure investment amplifies R2 but cannot address the B3 fragility accumulation R2 simultaneously drives. They are politically tractable; their B3 consequences are not. *Feedback loop interventions* are medium to high leverage: deliberate B6 activation shifts the dominant feedback governing information diffusion, and direct investment in recovery potential maintenance targets the Adaptive Capacity stock whose depletion generates the fragility trap, the intervention most consistently absent from development program budgets, for the same reason B3 is invisible to standard monitoring. *Goal and information structure interventions* are highest leverage: reframing the aspiration gap as a resilience gap, the difference between current recovery potential and a target defined by the system's hazard exposure, would reconfigure what households and policymakers treat as success. This requires changes to what programs measure, report, and reward, and is the most contested intervention precisely because it is the most structurally consequential.

7.3 The Archetype as Diagnosis, Not Prescription

System archetypes reveal structural tendencies; they do not constitute policy prescriptions. A system exhibiting strong R1 dominance in early transition requires infrastructure pre-loading. A structurally identical system in which B3 is already deeply operative requires immediate recovery potential investment regardless of income indicators. A post-saturation system where B5 has shifted dominance requires market coordination, not infrastructure investment. The same archetype, three entirely different policy responses, determined by current system state, not by the archetype alone. The five-indicator monitoring dashboard of Section 6 is precisely the state estimation tool bridging structural diagnosis to context-specific policy design.

Speed Versus Extent in Transformation Governance. The Planetary Boundaries framework (Rockström et al., 2009) asks where humanity must not go in terms of the extent of Earth system transformation. The Delayed Reward Trap addresses a complementary question: how fast must we not go there. Together they complete a two-dimensional framework for transformation governance, the envelope of safe outcomes (extent) and the envelope of safe pathways (rate).

The Delayed Reward Trap Among Existing Archetypes. The archetype is a distinct addition to the canonical SD library (Senge, 1990; Sterman, 2000), distinguished by three structural features: the *double ratchet* (both Perceived Income and Social Aspiration Level accumulate upward but cannot fall — no existing archetype combines two asymmetric accumulation stocks in this way); *endogenous hazard exposure* (B4 makes vulnerability endogenous to the transition itself, unlike Limits to Growth where constraint is exogenous to adoption); and *structural inversion across contexts* (unlike Fixes That Fail, which is context-invariant, the Delayed Reward Trap generates structurally opposite behavioral modes under polarity inversion). The archetype generalizes beyond HKH: Cochrane's (1958) Technology Treadmill exhibits the aspiration ratchet and infrastructure delay with fragility accumulation through capital concentration; urban household debt spirals share the double-ratchet

structure with collapse activated by discrete income shock; and rural-to-urban migration in Sub-Saharan Africa follows a push-driven Bhutan-type inversion. The Delayed Reward Trap provides the structural vocabulary for diagnosing and designing against this class of failure wherever it occurs.

The structural analysis has been translated into an open interactive simulation tool, following the design philosophy of En-ROADS (Sterman et al., 2020), that allows M&E practitioners and policy actors to run scenario experiments against the archetype's feedback structure without computational modeling background. We are actively working with ICIMOD project managers to apply the models to real monitoring data from Nepal, Myanmar, and Bhutan, and to develop the tool in a form that is accessible to practitioners in contexts of data scarcity, where proxy indicators must substitute for direct measurement and where policy decisions must be made with incomplete information. The tool is not context-locked to the HKH; it is applicable wherever the Delayed Reward Trap's feedback structure governs livelihood transition dynamics.

8. Limitations

Explicit acknowledgment of model boundaries is a scientific requirement, not a concession to incompleteness (Sterman, 2000, p. 159). Four structural omissions are consequential for policy application. Political Economy and Governance: The archetype models infrastructure investment as a function of household income and aspiration, not as a contested resource allocated through power relations, institutional inertia, and elite capture. A governance-extended version would require a loop structure representing political allocation of infrastructure as a function of power distribution rather than income. Collective Action Failure: The archetype aggregates household transition decisions through contagion and income diffusion, assuming each household decides independently. It cannot represent collective action failure when simultaneous uncoordinated entry collapses market prices. B5 loop dynamics are likely underestimated where rapid simultaneous adoption and fast price transmission co-occur. Climate non-stationarity: The archetype assumes a stationary hazard regime with fixed λ and damage magnitude. Under increasing hazard frequency, the Gap Indicator threshold becomes progressively narrower. A non-stationary extension would replace fixed λ with $\lambda(t) = \lambda_0 \times (1 + g)^t$, allowing threshold recalibration as the hazard environment evolves. Gender Disaggregation: The archetype aggregates households without gender differentiation, a behavioral accuracy concern, not only an equity one. A gender-disaggregated extension requires at minimum two aspiration stocks, differentiated access parameters, and separate vulnerability coefficients. Feedback mechanisms, loop dominance ordering, and threshold dynamics are robust at the level of qualitative behavior. Specific numerical thresholds, Gapcritical, CSIsafe, and safe-rate bound parameters, are structurally-derived reference values requiring validation against field monitoring data before deployment.

9. Conclusion

Rural livelihood transitions in the HKH are better understood as feedback processes than as development outcomes. Aspiration, income, social learning, resource constraint, and physical hazard interact across multiple timescales to produce outcomes that frequently diverge from the intentions of both the households experiencing them and the programs designed to support them.

The central contribution is the identification and formal specification of the Delayed Reward Trap as an identifiable system dynamics archetype recurring across Nepal's cereal-to-vegetable transition, Myanmar's agricultural-to-secondary-vocation transition, and Bhutan's yak herding departure, despite profound differences in ecology, culture, and institutional context. Four theoretical contributions emerge from this: the distinction between cash-flow fragility (B2a and B2b, visible) and structural fragility (B3, latent until shock); the B4 polarity inversion establishing that diversification's effect on vulnerability is context-dependent; conditional polarity reversal as a theoretical property demonstrated through the Bhutan cross-validation; and the $R3 \leftrightarrow B6$ information bifurcation establishing information infrastructure as a delivery mechanism rather than a policy instrument.

These converge on a single M&E implication. The Co-Scaling Index detects rate-coupling failure before it manifests as income collapse. The Gap Indicator detects income buffer erosion as it accumulates. Together they catch the Delayed Reward Trap at two distinct points in its development, giving program managers the structural warning time that current frameworks do not provide. The tool is not context-locked to the HKH; ongoing validation workshops with ICIMOD are progressively grounding the structural findings in field experience and ensuring the framework is actionable for the M&E professionals and policy advisors who constitute its primary user community.

The failure of livelihood transition systems is not a failure of effort or intention. It is a failure of synchronization, between the rate at which aspirations are formed and the rate at which the structural conditions for their fulfillment are built. The design principles and monitoring framework presented in this paper are the structural specification of what it would take for it to succeed.

[References in references document file]