Beyond Limits to Growth:

Why and How World3 and Previous Limits to Growth Models Fail

A Variety-Dynamics Analysis

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Executive Summary

The Limits to Growth (Limits to Growth) study, first published in 1972 and updated multiple times since, represents a landmark attempt to formally model global industrial-ecological-population dynamics. Its core analytical tool, the World3 system dynamics (System Dynamics) model, correctly identified that the global situation exceeds the two-feedback-loop boundary of human mental prediction capacity, requiring formal mathematical modelling (Axiom 49). This identification remains one of the study's genuine and enduring contributions.

However, Limits to Growth and its successors had a foundational category error that no amount of recalibration, parameter refinement, or computational sophistication can correct.

The researchers applied a causally analytic and modelling methodology, System Dynamics, that requires the situation to conform to the prerequisites of causally analysing s system. System dynamics modelling requires stable boundaries, stationary causal relationships, valid global aggregation, and closed system structure. The global industrial-ecological-population dynamics violates all four requirements across the 1900–2100 modelling horizon. System Dynamics, and similar approaches (e.g. agent-based and discrete element modelling) are inapplicable because those preconditions are not satisfied.

This category mismatch means World3 does not model the actual global situation. It models a hypothetical closed system that shares surface statistical features with the actual situation during its growth phase.

World3 and previous Limits to Growth models differ in precisely the properties that govern long-run behaviour near and beyond the inflection point. The extensive empirical validation literature, e.g. Turner (2008, 2012, 2014), Herrington (2021), Nebel et al.(2023) validates this hypothetical system only against historical data from the actual situation's growth phase. This is real evidence that the hypothetical system was well-parameterised for that phase.

However, this correlation of early data is not, and cannot be, validation that the actual situation will follow the hypothetical system into collapse, because the actual situation's future trajectory will be governed by precisely the properties the hypothetical system excludes.

Variety Dynamics analysis offers advantages over System Dynamics in this situation. Variety Dynamics operates through an axiomatic framework grounded in set theory and higher category/topos theories, rather than the causally-based differential equations and causal closure of System Dynamics.

Variety Dynamics was created to analyse *situations* rather than *systems*. *Systems* conform to the requirements described above, necessary to legitimately apply causally-based analysis and modelling such as System Dynamics. *Situations* are different. *Situations* do not conform to the requirements necessary for causally-based analysis and modelling.

The global industrial-ecological-population *situation* is not a *system*.

Applied to the global industrial-ecological-population situation, Variety Dynamics reveals structural features invisible to any system or causally-based model. It reveals, for example, deep constituency-level variety asymmetries that determine whose interests shape the situation's evolution (Axioms 1, 11); open boundary dynamics through which variety flows across the model's assumed closure (Axioms 15, 29, 31); the Nyquist-governed instability does make overshoot dynamically plausible but its timing is not represented by System Dynamics model's crude delay representations (Axiom 16); power law distributions of control variety concentrate leverage in small numbers of actors and mechanisms (Axioms 39, 40); and reveals the expectation of discontinuous rather than smooth collapse trajectories (Axiom 48).

Most consequentially for policy, Variety Dynamics reframes the central questions. Where System Dynamics simplistically asks: when will collapse occur? Variety Dynamics asks: who currently controls the variety distributions that govern the situation's trajectory, through what feedback mechanisms is that control maintained, and what redistribution mechanisms exist?

System Dynamic's question problematically and mistakenly presupposes the world situation is a *system* with a determinable causal trajectory.

In contrast, the questions Variety Dynamics poses produce actionable intelligence that System Dynamics unreliable trajectory predictions cannot provide, and Variety Dynamics does this regardless of whether elements of the situation satisfy causal analysis preconditions or not.

System Classification and Analytical Challenge

The Subject Matter: A Situation, Not a System

Type: Hyper-complex open global situation involving industrial-ecological-population dynamics across multiple constituencies, jurisdictions, and temporal scales, operating far beyond causal analysis preconditions.

Classification: *Situation*. The global industrial-ecological-population dynamics fails all preconditions necessary for valid causal/systems analysis:

Boundary instability: What constitutes the relevant system, which resources, which pollutants, which populations, which economic activities, has shifted fundamentally across the 1900–2100 modelling horizon. The emergence of synthetic materials, digital economies, nuclear energy, genetic modification of food crops, and atmospheric CO_2 as a primary driver all represent boundary shifts that are not exogenous perturbations to a stable system but transformations of the situation's causal architecture itself.

Non-stationary causal relationships: The functional relationships between industrial output and pollution, between food production and population, between resource depletion and capital costs, have been structurally transformed by institutional, technological, and political changes. The relationship between energy consumption and GDP that held in 1970 bears no stable resemblance to the relationship in 2025. The Green Revolution transformed the agricultural yield-capital relationship discontinuously. These are not parameter shifts within a stable functional form. They are transformations of the functional form itself.

Invalid global aggregation: The situation involves multiple constituencies, nation-states, corporations, demographic groups, ecological regions, with radically different variety generation and control capacities. Aggregating China, the United States, sub-Saharan Africa, and oil-producing states into a single "global industrial output per capita" produces a variable that is not causally connected to anything in the way the model assumes, because the mechanisms governing each constituency's trajectory are structurally different.

Open system dynamics: The situation is embedded in open networks of geopolitical, financial, institutional, and ecological variety flows that cannot be specified as exogenous inputs because they are endogenously generated by the situation itself in ways that feedback on it.

These failures are not modelling limitations correctable by better parameterisation or finer resolution. They are properties of the situation that place it in the category Axiom 50 defines as hyper-complex: a situation where "boundaries shift, feedback loops emerge or dissolve, relationships transform, and causal architectures evolve" such that "assumptions necessary for causal analysis" are violated.

Complexity Characteristics: The global situation operates through a minimum of twenty interacting feedback loops spanning resource depletion and extraction cost dynamics, population-food-mortality relationships, industrial capital accumulation and depreciation, pollution generation and absorption, agricultural land development and degradation, technological innovation and diffusion, geopolitical resource competition, financial capital flows, institutional regulatory responses, and demographic momentum structures. These loops interact across timescales ranging from annual harvest cycles to multigenerational demographic waves to centennial geological and atmospheric processes.

This structure places the situation far beyond the one -feedback-loop boundary of human mental prediction capacity (Axiom 49). No individual or group, however expert, can mentally track the dynamic consequences of interventions propagating through twenty interacting loops. This is not a limitation of expertise or effort. It is a fundamental cognitive boundary.

The Analytical Challenge: The situation's hyper-complexity means that conventional causal analysis and system dynamics modelling, tools appropriate for systems, not situations, cannot produce reliable predictions. However, this does not mean the situation is analytically intractable. Variety Dynamics provides an analytical framework appropriate for hyper-complex situations, operating through variety distribution analysis, feedback loop structure mapping, and locus-of-control identification rather than causal trajectory prediction.

Methodology Under Analysis: System Dynamics as a System

A critical distinction structures this case study. The subject matter being modelled, the global industrial-ecological-population dynamics, is a *situation*. The methodology used to model it, System Dynamics, is itself, if internally consistent, a *system*: it satisfies the preconditions for causal analysis of the methodology itself.

System Dynamics has: A stable, defined boundary (the assumptions, procedures, and formalisms that constitute valid System Dynamics practice); stationary causal structure (the rules governing how causal loop diagrams translate to stock-flow structures and computational implementations do not change between applications); identifiable, consistent relationships between components (the methodology's internal logic is stable and formally specifiable); closure (System Dynamics methodology is self-contained as a formal procedure).

This means System Dynamics can be validly critiqued on its own terms, assessed for internal consistency, evaluated for whether implementations correctly follow methodological rules, and improved within its own framework. The substantial literature critiquing World3's parameterisation, delay specifications, and functional forms operates within this legitimate space.

But the category distinction between System Dynamics-as-*system* and the global *situation*-as-situation has a consequence that this internal critique cannot address: **a**

methodology that is itself a system cannot be validly applied to a subject matter that is a situation.

The System Dynamics methodology's requirements, stable boundary, stationary relationships, valid aggregation, causal closure, are precisely what the situation fails to provide. Applying System Dynamics to the global situation involves substituting a tractable hypothetical system for the intractable actual situation, then analysing the hypothetical system as a proxy.

This substitution is not neutral. The hypothetical system's behaviour, including its collapse trajectory, is partly determined by the methodological requirements imposed on it, not solely by the properties of the actual situation. The collapse is not only a finding about the world; it is partly an artefact of the analytical category imposed on it.

What World3 Gets Right: A Variety Dynamics Assessment

Before developing the critique, intellectual honesty requires acknowledging what World3 correctly identifies and why those identifications retain value.

The Formal Modelling Requirement

The Meadows team's central insight, that the global situation has too many interacting feedback loops for human mental prediction, directly anticipates Axiom 49: "Systems are distinguished by their feedback loop structure relative to the two-feedback-loop boundary of human mental prediction capacity... complex systems (two or more feedback loops, formal modelling required)."

In 1972, this was a non-trivial and contested claim. The conventional policy response to global resource and environmental challenges was discursive and qualitative, expert panels, scenario narratives, committee deliberations. The Limits to Growth team's insistence that the situation's feedback complexity required formal mathematical modelling was methodologically correct, even if the specific form of modelling they chose was, as we argue, categorically misspecified.

This contribution remains significant. Much contemporary policy analysis of global sustainability challenges still operates through mental models and discursive reasoning that Axiom 49 identifies as structurally inadequate for situations with two or more feedback loops. The Meadows team's diagnosis of this inadequacy was right.

The Nyquist-Governed Delay Structure

Axiom 16 establishes: "Stable control of simple systems is defined by the Nyquist number. The Nyquist number indicates whether the relationship between the control system and deviation-causing subsystems or external factors is likely to become stable, oscillatory or trend towards an unstable or even unknown outcome."

World3's delay structure, industrial capital lifetime of approximately 14 years, pollution absorption delays of decades, agricultural land development lags, demographic momentum extending 40–70 years, captures something real about the actual situation. These delays are not modelling artefacts; they reflect genuine physical and biological timescales. Resource depletion really does take decades to manifest as cost increases. Population really does have multi-generational momentum. Pollution really does accumulate over decades before ecological impacts fully register.

The consequence that Axiom 16 identifies, that systems with long delays relative to growth rates exhibit instability, oscillation, or trend toward unknown outcomes, is a genuine structural feature of the global situation. The overshoot attractor that World3 produces is not purely a model artefact; it reflects a real dynamic in which the feedback delays governing human institutional and biological response are long relative to the timescales of resource depletion and pollution accumulation.

What World3 cannot determine, and what Axiom 16 does not pretend the Nyquist analysis alone can determine, is the precise timing and character of that instability. The delays in the model are estimates from limited OECD data (as discussed below), and the interaction of multiple delays in a hyper-complex situation produces behaviour that cannot be reliably extrapolated from the model's simplified representation.

The Growth Phase Parameterisation

The empirical validation work, Turner (2008, 2012, 2014), Herrington (2021), Nebel et al.(2023), demonstrates that the World3 model, when parameterised against data from the actual situation's growth phase, tracks historical trajectories of population, industrial output, food production, and pollution reasonably well through approximately 2020. This is real evidence that:

1. The model's initial conditions were reasonably well specified
2. The growth dynamics of the hypothetical system approximate the growth dynamics of the actual situation in the pre-peak regime
3. The aggregate trajectories of the actual situation, at the global level, have followed exponential growth patterns consistent with the model's structure

This is not nothing. It means the model is not merely speculative, it has genuine empirical grounding for the regime it was designed to represent. Variety Dynamics analysis does not dismiss this evidence; it contextualises it. The growth phase fit tells us about the pre-inflection regime.

The critical question, how the actual situation will behave at and beyond the inflection, is precisely where the category difference between *situation* and *system* becomes dynamically consequential.

The Category Error: Applying a System Methodology to a Situation

What the Conversion Requires

To apply System Dynamics methodology to the global situation, the Meadows team necessarily converted the situation into a system by imposing:

Closed boundary: World3 excludes geopolitics, institutional change, financial systems, and technological discontinuities as modelled endogenous variables. These appear, if at all, as exogenous parameters, things that happen to the system from outside rather than being generated within it. But in the actual situation, geopolitical competition over resources, institutional responses to scarcity, financial capital flows, and technological innovation are endogenously generated by the situation itself and feed back on its trajectory. The boundary closure is not a simplifying approximation. It excludes the mechanisms most likely to determine whether and how the actual situation's trajectory diverges from the model's.

Stationary functional relationships: The TABLE functions encoding how industrial output responds to resource depletion, how agricultural yield responds to capital investment, how pollution affects mortality, were estimated from data available in 1970–1972 and encoded as fixed functional forms. In the actual *situation*, these relationships have been structurally transformed multiple times since 1972, by the Green Revolution, by energy efficiency improvements, by synthetic materials substitution, by digital dematerialisation, by environmental regulation. World3's functional forms do not represent these transformations because, as a *system* model, it requires the functional relationships to be stable.

Global aggregation across heterogeneous constituencies: The system model represents the world as a single undifferentiated entity with global-mean values for all variables. This aggregation erases the constituency structure that Axioms 1 and 11 identify as foundational to how the situation actually operates. The asymmetries between constituencies, in variety generation capacity, in resource consumption, in pollution generation and exposure, in institutional response capability, are not noise around a global mean. They are the primary drivers of the situation's actual trajectory.

Fixed causal architecture: The causal loop diagram underlying World3 was drawn in 1970–1972 and has been refined but not structurally transformed in subsequent versions. In the actual situation, the causal architecture has evolved: the financialisation of commodity markets created new feedback loops not present in 1972; the digital economy changed the relationship between industrial activity and resource consumption; climate change created new feedback mechanisms (permafrost methane, ice-albedo) that were not modelled. These are not new variables to add to an existing structure. They represent transformations of the causal architecture itself.

The Consequence: Two Different Objects

The consequence of this conversion is that World3 and the actual global situation are two different objects:

World3 is a hypothetical closed *system* with fixed functional relationships, global-mean variables, and a causal architecture frozen in 1970–1972, parameterised against data from the actual situation's growth phase.

The actual global situation is a hyper-complex open *situation* with evolving causal architecture, heterogeneous constituencies, non-stationary functional relationships, and open boundary dynamics.

These objects share the same growth-phase trajectory because the growth phase is dominated by simple exponential dynamics that any reasonable model with correct initial conditions and growth rates will reproduce. They will diverge, potentially substantially, at and after the inflection point, because it is precisely there that the properties excluded by the conversion (institutional responses, technological discontinuities, constituency dynamics, open boundary flows) become the dominant determinants of trajectory.

The validation literature cannot detect this divergence because it has only historical growth-phase data to compare against, which is exactly the regime where the two objects agree. Axiom 32 establishes: "Counterfactuals and varieties correspond exactly, both represent multiple possible states or representations of a situation." The validation literature compares one specific historical trajectory against the model's output. But the actual situation contains the variety of multiple possible trajectories, and the model's structure determines which of those trajectories it can represent, independently of which actually occurred.

Representational Limitations Within the System Model

Even accepting, for the sake of argument, that System Dynamics methodology was appropriate for the global *situation*. That is, setting aside the category error entirely. World3's specific implementation introduces further distortions through its representational choices. These are limitations within the *system* model itself, distinct from and additional to the category error. They bear on the reliability of collapse timing predictions and on whether the smooth decline trajectory the model produces is an artefact of representation rather than a genuine finding about system behaviour.

Numerical Integration: Euler's Method and the Stiffness Problem

World3 was implemented in DYNAMO using first-order explicit Euler integration with a fixed timestep of DT = 0.5 years. This is the most primitive numerical integration scheme available. Its limitations for World3 are substantial.

Euler integration is only first-order accurate, local truncation error is $O(DT^2)$ and global error accumulates as O(DT) over 260 steps across the 130-year simulation. More critically, Euler integration is conditionally stable: for stiff systems, systems with processes operating across widely separated timescales, it can introduce spurious dynamics or numerical instabilities that mimic real system behaviour without representing it.

World3 (but not the actual world) is a stiff system. It contains processes operating across timescales from less than one year (annual agricultural adjustment) to approximately 14 years (industrial capital depreciation) to decades (pollution absorption) to generations (demographic momentum of 40–70 years). Modern stiff solvers, implicit Runge-Kutta methods, Rosenbrock methods, Gear's method, handle this through adaptive timestepping that maintains stability regardless of the timescale ratio. Euler integration with fixed DT = 0.5 may violate stability conditions for the fastest modes, introducing numerical dissipation that artificially couples processes across timescales.

The consequence, from a Variety Dynamics perspective, is that some of the model's dynamic behaviour may reflect the numerical method's interaction with the delay structure rather than the underlying relationships. Axiom 17 establishes: "The variety dynamics function describing the behaviour exists as a meta-function or collection of functions that maps to the relations between the control system varieties, the disturbing system varieties and the varieties of the behaviours resulting from the interaction." The Euler integration artefacts introduce a meta-level distortion: the variety of behaviours the model can produce is partly constrained by the numerical method, not solely by the modelled relationships. The Nebel et al. recalibration using Python likely employed an adaptive stiff solver, which may partly explain parameter shifts even before empirical recalibration, since the numerical artefacts differ between implementations.

TABLE Functions: Piecewise-Linear Approximations to Continuous Relationships

World3 encodes nonlinear relationships through DYNAMO TABLE functions, piecewise-linear lookup tables mapping input values to output values through linear interpolation between hand-estimated points. These tables encode relationships such as how death rate varies with food per capita, how industrial output responds to resource depletion fraction, and how pollution affects agricultural yield.

The representational consequences are significant. Piecewise-linear functions have discontinuous first derivatives at knot points. They introduce artificial kinks into the phase space. These kinks can create or destroy attractors, alter bifurcation structure, and generate artefactual dynamical behaviour absent from the smooth underlying relationships they approximate. A smooth sigmoid relationship and its piecewise-linear TABLE approximation can have qualitatively different stability properties, different numbers of equilibria, different basin boundaries, different bifurcation sequences.

Furthermore, TABLE functions are static, they encode the relationship as estimated circa 1970–1972, with no capacity for the functional form itself to evolve. In the actual situation, as argued above, the functional forms of key relationships have been structurally transformed. But the TABLE function representation cannot represent this transformation even if better data were available, because it encodes a point estimate of the relationship, not a distribution of possible relationships or a meta-function describing how the relationship itself varies.

From a Variety Dynamics perspective, the TABLE functions are zeroth-order hold reconstructions of continuous relationships, precisely the representation class that introduces maximum phase lag in a sampled-data system, directly compounding the Nyquist delay analysis of Axiom 16. The collapse timing the model predicts is partly determined by the phase lag introduced by these representational choices, not solely by the actual delay structure of the global situation.

First-Order Delay Structures and Phase Margin

World3 implements delays through DYNAMO SMOOTH and DELAY functions, primarily first-order exponential smoothing structures with transfer functions of the form $1/(\tau s + 1)$. First-order delays add 90° of phase lag asymptotically and have gentle roll-off characteristics. The model does use some third-order Erlang chain delays (DELAY3) for specific variables, but the predominant delay representation is first-order.

Real physical, biological, and social delays are almost never first-order. They typically involve distributed delays (better represented by higher-order Erlang chains or gamma distributions), pipeline delays (pure time delays with transfer functions e^{-sT}), and threshold-activated responses (nonlinear delays that activate only above certain thresholds). The choice of delay order directly and systematically affects the Nyquist phase margin analysis identified in Axiom 16:

Replacing first-order delays with third-order delays of equivalent mean delay time produces substantially more phase lag at relevant frequencies, moving the system deeper into the instability region and shifting collapse earlier. Replacing first-order delays with pure pipeline delays of equivalent mean produces maximum phase lag, representing the hardest possible stability constraint. Conversely, incorporating anticipatory or learning elements (equivalent to phase lead compensation) would shift the system toward greater stability.

The original authors had essentially no basis for choosing delay orders beyond computational tractability in 1970s DYNAMO. This is not a criticism of their choices. The alternatives were not computationally accessible. But it means that the model’s collapse timing is systematically sensitive to representational choices that were made on grounds of computational convenience rather than empirical estimation. A systematic representation sensitivity analysis, replacing TABLE functions with smooth parametric forms, replacing first-order delays with higher-order distributed delays, and solving with an adaptive stiff solver, would separate what the model genuinely says about the situation from what the representation imposes on the model. To our knowledge, this analysis has not been performed rigorously in the published literature.

The Topological Consequence: Is Collapse Robust or Artefactual?

The representational limitations raise a precise and important question: is the World3 collapse trajectory a robust finding about the behaviour of any reasonable model of the global situation with similar causal structure, or is it partly an artefact of the specific representational choices made in 1970–1972?

This question has a direct bearing on how to interpret the recalibration literature. Nebel et al.'s finding that the recalibrated model shows "the same overshoot and collapse mode" tells us that the collapse is robust to parameter changes within the World3 representational framework. It does not tell us whether the collapse is robust to representational changes, to different numerical methods, different functional form specifications, different delay order choices.

From a Variety Dynamics perspective, the question maps onto Axiom 16's Nyquist analysis: the collapse attractor exists because the system's delay structure places it in the unstable region of the Nyquist diagram. But the precise location in that diagram, how deep into the instability region, how far from the boundary, is sensitive to representational choices governing phase lag. TABLE functions maximise phase lag through their zeroth-order hold structure. First-order delays are a specific point in the space of possible delay representations. The hypothetical system's collapse trajectory is partly a reading of these representational choices, not purely a reading of the actual situation's delay structure.

This does not mean the collapse finding is wrong. It means the model cannot tell us, from within its own representational framework, whether its collapse trajectory is a robust finding about the class of models with similar causal structure, or a specific artefact of its particular representational choices. Answering that question requires the representation sensitivity analysis that remains absent from the literature.

Variety Distribution Analysis: What World3 Cannot See

Constituency Variety Asymmetries

Axiom 1 establishes: "In complex and hyper-complex systems involving multiple constituencies where variety generation and control distribution is uneven, the differing distributions and dynamics of generated and controlling variety create a structural basis for power asymmetries and differential control over the system's structure, evolution, and distribution of benefits and costs."

World3 has no constituencies. It has global aggregates. This is not merely an omission. It excludes the very mechanism that Axiom 1 identifies as foundational to how the situation operates.

The actual global situation involves constituencies with radically different variety portfolios:

High-variety constituencies: OECD nations with diversified economies, strong institutional capacity, technological innovation systems, financial market access, and political influence over global institutions. Fossil fuel producing states with concentrated resource control varieties. Multinational corporations with cross-boundary operational varieties, legal flexibility, and political access varieties across jurisdictions. Financial institutions with capital allocation varieties determining which technologies and regions receive investment.

Low-variety constituencies: Sub-Saharan African nations with limited industrial capacity, high resource exposure, minimal political influence over global institutions, and high vulnerability to both resource price shocks and pollution consequences. Small island states facing existential climate consequences from pollution generated primarily by high-variety constituencies. Agricultural communities in developing nations whose food security depends on rainfall and temperature regimes shaped by industrial activity in which they have no meaningful participation.

Axiom 11 identifies the consequence: “The differing distributions of generated and controlling variety result in a structural basis for differing amounts of power and hegemonic control over the structure, evolution and distribution of benefits and costs of the system by particular constituencies.”

The actual global situation is characterised by extraordinary asymmetry in who generates the variety that drives the situation (primarily high-income industrialised economies and their associated corporations) and who bears the costs of that variety generation (disproportionately low-income populations and future generations). This asymmetry is not a secondary feature of the situation, it is, from a Variety Dynamics perspective, its primary structural characteristic.

World3’s global aggregation renders this structure invisible by design. The model produces a single global trajectory for industrial output, food per capita, and pollution, averages across a distribution of constituency experiences that are becoming more, not less, divergent over time. The “collapse” the model predicts is a collapse of the global mean. The actual situation may produce regional collapse for low-variety constituencies while high-variety constituencies maintain their trajectories through variety substitution and resource access advantages, an outcome qualitatively different from the model’s uniform global decline, and one that changes the policy implications fundamentally.

The Data Provenance Problem as a Variety Asymmetry

The geographic data bias identified in our preceding analysis, World3 being parameterised primarily from US, Western European, and Japanese data, is itself a variety asymmetry operating at the level of the modelling process. The constituencies whose data was unavailable or excluded in 1970–1972, China, the Soviet Union, India, sub-Saharan Africa, collectively represented the majority of world population and, in subsequent decades, the majority of global industrial growth.

Axiom 25 establishes: "All situations that process or contain variety can be viewed through an information systems lens. The transformation from real-world situation to information system and subsequent processing within the conventions of information systems always involves representational loss, increasing informatic entropy."

The parameterisation process converted the global situation into an information system by representing it through data available in 1970–1972 OECD statistical systems. This conversion involved systematic representational loss: the functional relationships of non-OECD economies, which would prove to dominate the subsequent trajectory, were absent from the calibration. The model's "world" is effectively the OECD world scaled to global means, a representation that captures approximately 15% of world population but 70% of the data infrastructure available at the time.

The consequence is that the model's functional forms, resource depletion cost curves, agricultural yield responses, capital depreciation rates, pollution generation coefficients, encode the dynamics of mature industrial economies at a specific stage of their development. When applied globally, they project those dynamics onto economies that are, and will remain, at different stages, with different institutional structures, different resource endowments, and different technological trajectories.

The Feedback Loop Control Structure

Axiom 10 establishes: "In complex and hyper-complex systems in which multiple and variable sources of variety generation and variety control interact AND in which control varieties are generated dynamically to respond to changes in system varieties THEN relative control of the feedback loops driving control varieties shapes the future distribution of power and hegemonic control."

World3 models feedback loops as mechanical physical relationships, population growth feeds back on food demand, industrial output feeds back on pollution generation. What it cannot model is the political economy of who controls which feedback loops and how that control determines the situation's trajectory.

In the actual global situation, the critical feedback loops are not merely physical, they are contested political and economic structures. The feedback between resource depletion and extraction cost is mediated by OPEC cartel behaviour, by national resource sovereignty decisions, by financial speculation in commodity futures markets, by technology investment decisions in extraction industries. The feedback between pollution accumulation and institutional response is mediated by the lobbying varieties of fossil fuel corporations, by the political variety asymmetries between polluting and polluted constituencies, by the international treaty negotiation dynamics captured partially in Axiom 33.

Axiom 41 identifies the consequence: "In complex situations, the locus of power can be changed by changes to variety distributions operating beyond the two-feedback-loop cognitive boundary. Such variety distribution changes and changes to the locus of power are effectively invisible to those affected."

The most important dynamics shaping the actual situation's trajectory, the variety manipulation strategies of high-variety constituencies to maintain their control over resource access and pollution consequences, operate through feedback structures invisible to the single-loop cognitive boundary and therefore invisible to the mental models of most policymakers. They are also, critically, invisible to World3, because the model encodes the feedback loops as physical relationships rather than politically contested variety control structures.

The Open Boundary Problem

Axiom 15 establishes: "Systems with variety dynamics do not necessarily have closed boundaries and outcomes and processes are only reversible in special instances."

Axiom 29 establishes: "Variety dynamics situations can be open systems. This capability is significant because most real-world variety processing occurs in open, interconnected networks rather than discrete bounded systems."

World3's closed boundary assumption excludes what are, from a Variety Dynamics perspective, the most important variety flows shaping the actual situation's trajectory. Three categories of excluded variety flows are particularly significant:

Geopolitical Variety Flows

The global situation is embedded in geopolitical structures that generate and redistribute variety in ways that directly affect resource extraction, pollution regulation, and technological diffusion. The OPEC oil embargo of 1973, occurring one year after Limits to Growth's publication, demonstrated that resource availability is not solely a function of geological depletion rates but is shaped by organised political variety generation by resource-controlling constituencies. The subsequent decades have repeatedly confirmed that geopolitical dynamics, sanctions, trade agreements, military conflicts over resource access, strategic technology transfer restrictions, are primary determinants of the resource-capital-pollution trajectories World3 models as physical relationships.

Financial System Variety Flows

Financial capital allocation is the primary mechanism through which investment in resource extraction, pollution control, and technological alternatives is determined in the actual situation. The financialisation of commodity markets from the 1990s onward created new feedback structures, commodity price speculation, derivatives-based resource hedging, carbon credit markets, that feedback on extraction rates, technology investment, and pollution trajectories in ways entirely absent from World3's structure.

Axiom 27 establishes: "In competitive situations between multiple actors, power and variety are interchangeable resources for influencing the locus of power and creating potential for control changes." Financial capital is a variety that is interchangeable with other varieties, it can purchase political influence, technological capability, resource access, and institutional influence. The global situation's trajectory is substantially determined by how financial varieties flow between constituencies and between investment categories. World3 has no representation of this mechanism.

Technological Discontinuity Flows

World3's comprehensive technology scenario, its most optimistic trajectory, assumes that technology deployment follows the model's resource substitution and pollution abatement parameters. But actual technological change in the actual situation is discontinuous, exhibiting the cusp-like behaviour Axiom 48 identifies: "Small continuous changes in input varieties produce discontinuous changes in system variety distributions."

The solar photovoltaic cost trajectory, an order of magnitude cost reduction between 2010 and 2024, is a discontinuous technological transition that no continuous-parameter model could have predicted or represented. Similarly, the shale gas revolution transformed the US resource depletion trajectory through a technological discontinuity that fundamentally violated World3's resource extraction cost function. These are not parameter shifts; they are structural changes in the variety distributions governing energy and resource systems.

The model's closed boundary means these discontinuities appear, if at all, only as exogenous shocks. In the actual situation, they are endogenous, generated by the situation's own dynamics, specifically by the feedback between resource scarcity signals and innovation investment, mediated by financial capital flows and geopolitical incentive structures. The boundary closure excludes the very mechanisms through which the actual situation might, or might not, avoid the hypothetical system's collapse trajectory.

Transaction Costs and the Comprehensive Technology Scenario

Axioms 34, 35, and 36 establish that: "The ability of a controlling or coercive agency to increase its variety to increase its potential for power and control is limited by the Coasian transaction costs associated with generating, using, and managing the additional variety"; "Coasian transaction costs associated with generating, using, and managing variety increase as variety increases"; and "Coasian transaction costs associated with variety increase exponentially or combinatorially with increases in variety, not linearly."

These axioms have a direct and largely unexamined bearing on World3's optimistic scenarios. The comprehensive technology (CT) scenario, where technology continuously substitutes for depleting resources and abates pollution, is the model's primary hope scenario. But deploying technology at planetary scale requires generating and managing variety of extraordinary complexity: technological variety (multiple different technologies for multiple resource types), institutional variety (regulatory frameworks, market mechanisms, international agreements), financial variety (investment capital allocation across technologies and regions), and coordination variety (managing the interactions between technology deployments across constituencies and timescales).

Axiom 36's exponential scaling means that the transaction costs of the CT scenario are not merely large, they grow exponentially with the number of resource-technology substitutions, pollution abatement mechanisms, and coordination requirements involved. World3 has no representation of these transaction costs. The CT scenario assumes that if the technology works physically, it will be deployed, that the variety of technological solutions translates directly into deployed capability. In the actual situation, the gap between available technology and deployed capability is determined by transaction cost dynamics that are among the most important obstacles to sustainability transition.

Axiom 37 adds: "When actors compete by manipulating variety distributions for advantage, transaction costs increase substantially compared to independent operation." The actual global situation involves intense competition between constituencies with opposing interests in technology deployment, fossil fuel industries with substantial political and financial variety invested in preventing rapid technology transition, emerging economies seeking the resource-intensive development path that industrialised economies took, and low-variety constituencies attempting to access clean technology without the financial varieties required to deploy it. This competition multiplies the transaction costs of the CT scenario beyond anything the model represents.

The consequence is that World3's CT scenario is not a realistic alternative trajectory for the actual situation, it is a physically possible trajectory for the hypothetical system, where transaction costs of technology deployment are implicitly assumed to be zero. For the actual situation, the transaction cost dynamics of large-scale technological transition constitute a primary determinant of whether any particular technology or policy intervention actually shifts the situation's trajectory.

Power Law Distributions and the Character of Collapse

Axiom 39 establishes: "At any point in time in any complex or hyper-complex situation, the control effects and benefits to specific stakeholders from particular varieties within a variety distribution follow power law distributions."

Axiom 40 extends: "Empirical evidence across many domains suggests the ways variety distributions and their dynamics shape the locus of control in situations often follow power laws, where a small proportion of variety distributions and changes to them account for disproportionate effects on the locus of power and costs."

World3 produces a smooth global multi-decade decline as the collapse trajectory, a gradual several-decade transition from peak to trough in industrial output, food per capita, and population. This smooth trajectory is an artefact of the model's continuous differential equation structure, global aggregation, and fixed functional forms. It does not represent the actual character of collapse in complex situations.

Axiom 48 establishes: "Variety distributions can contain regions where they become discontinuous, exhibiting boundaries or cusp-like behaviours. At these discontinuities, the variety landscape itself has discontinuous structure, creating critical boundaries where small continuous changes in input varieties produce discontinuous changes in system variety distributions. These discontinuities mark points of irreversibility in variety transformations."

Historical evidence from actual complex situation collapses, the Bronze Age Collapse (~1200 BCE), the Western Roman Empire, the Classic Maya, Soviet economic collapse (1989–1991), consistently shows discontinuous, rapid, and regionally differentiated collapse rather than the smooth global decline World3 produces. These historical collapses exhibit power law dynamics: cascading failures propagating through interconnected variety networks, where small numbers of critical variety failures trigger disproportionate systemic consequences.

The Nebel et al. recalibration finding, that peaks move slightly later and higher, is consistent with this analysis. Technology and resource efficiency have extended the growth phase, as Dennis Meadows always noted: "Technology can delay a peak, but the crash comes harder when it comes." From a Variety Dynamics perspective, this is an Axiom 48 prediction: extending the growth phase through technology deployment increases the height of the peak and the steepness of the discontinuity when critical variety thresholds are crossed. The recalibrated model's smooth decline trajectory still fails to capture the discontinuous character that Axiom 48 predicts for the actual situation.

The power law distribution of variety control (Axioms 39, 40) further shapes the character of likely collapse. In the actual global situation, small numbers of critical variety concentrations, oil exporting states controlling energy variety, major grain-producing nations controlling food variety, reserve currency nations controlling financial variety, account for disproportionate stabilising effects. Their disruption would not produce smooth global mean decline; it would produce cascading variety failures propagating through the open networks that World3's closed boundary excludes.

The Locus of Control: What Variety Dynamics Reveals That System Dynamics Cannot

Axiom 41 establishes: "In complex situations, the locus of power can be changed by changes to variety distributions operating beyond the two-feedback-loop cognitive boundary. Such variety distribution changes and changes to the locus of power are effectively invisible to those affected. Mapping the feedback loop structure and variety distributions enables situational awareness of hidden pathways shaping power and control via variety manipulation."

The most fundamental difference between what Variety Dynamics analysis and System Dynamics modelling reveal about the global industrial-ecological-population situation is the shift from trajectory prediction to locus-of-control identification.

World3 asks: given the current state of the world, what trajectory will global variables follow? This is a causal prediction question. It presupposes the situation has a determinable trajectory, which, as we have argued, presupposes the situation is a system.

Variety Dynamics asks: who currently controls the variety distributions that shape the situation's evolution, through what feedback mechanisms is that control maintained, and what mechanisms are available to redistribute it? This is a structural question answerable for situations regardless of whether they satisfy causal analysis preconditions.

Current Locus of Control in the Global Situation

High-variety controlling constituencies:

Fossil fuel corporations and producing states possess resource variety (proven reserves), financial variety (capital for extraction infrastructure), political variety (influence over international energy governance), and strategic variety (ability to modulate supply to shape prices and policy). Their variety portfolios give them substantial control over the energy-pollution feedback that World3 represents as a physical relationship. The actual feedback involves deliberate variety generation and deployment by these constituencies to maintain their control.

Financial institutions and capital allocators control investment variety that determines which technologies receive development capital, which regions receive industrial development investment, and which resource extraction projects are funded. The financial sector's variety portfolios effectively determine the technological and regional distribution of industrial activity. This is a control mechanism entirely absent from World3.

OECD-nation governments and international institutions control institutional variety, the rules, standards, and agreements that govern resource access, pollution rights, and technology transfer. The distribution of institutional variety determines which constituencies bear the transaction costs of sustainability transitions and which receive the benefits.

Low-variety constituencies bearing disproportionate costs:

Low-income nations, small island states, agricultural communities dependent on stable rainfall and temperature, and future generations possess minimal variety relative to the costs imposed on them by the situation's current trajectory. Their limited political variety, financial variety, and institutional variety mean they have negligible influence over the variety distributions that govern the situation's evolution, despite bearing disproportionate exposure to its consequences.

Axiom 43 identifies the governance consequence: "It is only possible to control variety of a security or similar situation by using more variety than the system being controlled. If the variety of the controlling system is attenuated, then the power of the controlling security is compromised."

The global institutional structures nominally tasked with managing the situation, the UNFCCC, the IPCC, the System Dynamics framework, possess dramatically less variety than the industrial-economic system they are attempting to regulate. Their variety portfolios (negotiated agreements, non-binding commitments, reporting requirements) are dwarfed by the variety portfolios of the constituencies they nominally govern (capital allocation power, technological capability, geopolitical leverage). Axiom 43 predicts that governance capacity is therefore structurally compromised, not because of implementation failure but because of fundamental variety deficit.

Axiom 44 reinforces this: "An organisation tends towards stability when the variety it controls exceeds the variety required for controlling its external environment, managing its internal operations, and pursuing its developmental ambitions." Global governance organisations consistently fail this condition. Their control variety is insufficient for the variety of the industrial-ecological situation they are attempting to manage.

The Activity/Redistribution Distinction Applied to Global Policy

A critical Variety Dynamics distinction, parallel to its application in the Variety Dynamic Shadow Banking and Snowy River case studies, applies directly to the Limits to Growth policy context. It is important to make a distinction between activity within a stable variety distribution and genuine variety redistribution that shifts the locus of control.

The fifty years since Limits to Growth's publication have generated extraordinary amounts of policy activity: the Rio Earth Summit (1992), the Kyoto Protocol (1997), the Millennium Development Goals (2000), the Paris Agreement (2015), the SDGs (2015), COP negotiations annually. This activity has produced commitments, frameworks, reporting systems, and institutional structures of considerable sophistication.

Yet the variety distributions that govern the situation's trajectory, who controls energy variety, financial variety, institutional variety, and technological variety, have not been fundamentally redistributed. Fossil fuel consumption continued increasing for most of the period. Wealth concentration increased rather than decreased. The variety asymmetry between high-income and low-income constituencies widened. Carbon emissions continued to rise until recently, and the cumulative atmospheric concentration grew regardless.

From a Variety Dynamics perspective, this pattern is not primarily a failure of political will or implementation. It reflects the structural consequence identified across the case studies and formalised in Axiom 51: “Events occurring within stable variety distributions do not shift power locus and consequent outcomes. Only decisions or interventions that actually redistribute varieties between actors change where control resides.” The policy activity since 1972 has been extensive. The variety redistribution has been minimal. The policy activity since 1972 has occurred within variety distributions that maintain the control of high-variety constituencies over the situation’s trajectory. No mechanism for genuine variety redistribution, one that actually transfers control variety from fossil fuel systems to renewable systems, from high-variety to low-variety constituencies, from present to future generation interests, has been implemented at sufficient scale to shift the situation’s fundamental trajectory.

Analytical Findings

Finding 1: World3 Is a System Model Applied to a Situation, the Category Error Cannot Be Corrected by Recalibration

Conventional view: World3 has been repeatedly validated against empirical data and its recalibration by Nebel et al. (2023) confirms its ongoing validity as a model of global dynamics.

Variety Dynamics reveals: The validation literature tests whether a system model was well-parameterised for the situation’s growth phase. This is a legitimate and valuable finding. However, the fundamental issue is not parameterisation but category: System Dynamics methodology requires the subject matter to be a system, and the global situation is not a system. No recalibration, however thorough, can correct a category error. The Nebel et al. finding, that the recalibrated model shows “the same overshoot and collapse mode”, demonstrates that the hypothetical system remains robustly in its collapse attractor. It does not demonstrate that the actual situation will follow the hypothetical system, because the actual situation’s trajectory will be determined by precisely the mechanisms (open boundary dynamics, constituency variety redistribution, institutional response, technological discontinuities) that the conversion to a system model excluded.

Evidence: The post-1972 trajectory of the actual situation has repeatedly diverged from World3’s hypothetical system in ways that reflect the excluded mechanisms: OPEC’s political variety generation transformed the resource depletion trajectory in 1973; the Green Revolution’s agricultural discontinuity transformed the food-population trajectory in the 1970s–80s; China’s rapid industrial development followed a trajectory that the model’s parameters could not accommodate; solar and wind energy costs collapsed orders of magnitude faster than any resource substitution parameter in the model could represent. In each case, the divergence reflects excluded open-boundary variety flows rather than parameter error.

Finding 2: The Validation Literature Validates the Wrong Object

Conventional view: The close tracking of World3's trajectories by historical data across 50 years of independent verification strongly supports the model's predictive validity.

Variety Dynamics reveals: The validation literature demonstrates that the hypothetical system's growth-phase trajectory approximates the actual situation's growth-phase trajectory. This tells us the model was reasonably parameterised for the pre-peak regime. It does not validate the model's behaviour at and after the inflection, where the properties excluded by the system conversion become dynamically dominant.

Applying Axiom 17: "The variety dynamics function describing the behaviour exists as a meta-function or collection of functions that maps to the relations between the control system varieties, the disturbing system varieties and the varieties of the behaviours resulting from their interaction." World3 operates at the object level, it models specific variable trajectories. Variety Dynamics operates at the meta-level., it analyses the variety of possible trajectory behaviours and what determines which trajectory the situation follows. The validation literature operates at the object level: comparing one trajectory against another. It cannot address the meta-level question of whether the model's trajectory is within the variety of trajectories the actual situation can follow.

Finding 3: The Overshoot Attractor Is Topologically Robust But Timing Is Ungoverned

Conventional view: Recalibration confirms both the reality of the overshoot-collapse trajectory and narrows the uncertainty about its timing.

Variety Dynamics reveals: The overshoot attractor is partly a topological consequence of the model's delay structure (Axiom 16), not solely a finding about the actual situation. Any model with net negative feedback operating through long delays around an integrating growth process will produce overshoot, the question is whether the actual situation's delay structure places it in the unstable region of the Nyquist analysis. The evidence that it does is real, but the model's quantitative specificity about timing is not supported by its data foundations. The parameters governing timing, particularly industrial capital lifetime, pollution absorption delay, and agricultural land development time, were estimated primarily from OECD data in 1970–1972, and their applicability to the actual global situation at the scale and heterogeneity required for reliable timing prediction is not established. Axiom 16 tells us the situation is likely in an unstable regime; it does not tell us the collapse peaks at the precise year World3 specifies.

Finding 4: Constituency Variety Asymmetries Determine Whose Interests Shape the Trajectory

Conventional view: The Limits to Growth situation is a shared global challenge requiring coordinated global response; the relevant actor is "humanity" or "global civilisation."

Variety Dynamics reveals: Applying Axioms 1 and 11, the actual situation involves structured power asymmetries in which particular constituencies, those with the highest variety portfolios in energy, finance, technology, and institutions, exercise disproportionate control over the situation's trajectory and receive disproportionate benefits from its current configuration. The "global civilisation" framing that Limits to Growth employs obscures these asymmetries and produces policy recommendations (broadly distributed global responsibility) that are structurally disconnected from the actual locus of control. Effective intervention requires identifying and engaging the specific high-variety constituencies whose control variety determines the situation's trajectory, not appealing to undifferentiated global humanity.

Finding 5: The Policy Question Must Be Reframed from Trajectory Prediction to Variety Redistribution

Conventional view: The Limits to Growth study's primary policy contribution is trajectory prediction, showing that 'Business As Usual" leads to collapse, motivating preventive action.

Variety Dynamics reveals: Applying Axiom 50, the global situation is hyper-complex and "requires Variety Dynamics approaches focusing on managing the locus of control rather than predicting causal outcomes." The trajectory prediction framing is not merely imprecise., it is structurally inappropriate for a situation that fails causal analysis preconditions. The actionable policy question is not "when will collapse occur?" but "what variety redistribution mechanisms are available, to which constituencies, at what transaction cost, and what shift in the locus of control would they produce?" These questions are answerable through Variety Dynamics analysis and produce intervention-relevant intelligence that trajectory prediction cannot provide.

Governance Implications: Managing the Locus of Control

The Requisite Variety Problem in Global Governance

Axiom 43 predicts that any governance system attempting to control the variety of the global industrial-ecological situation must possess greater control variety than the situation generates. The actual global situation generates variety at rates and through mechanisms, technological innovation, geopolitical competition, financial product development, ecological feedback, that dramatically exceed the control variety of current global governance institutions.

This is not primarily a problem of political will or institutional design, though both matter. It is a structural variety deficit: the variety generation capacity of the global industrial-economic system exceeds the control variety of any conceivable global governance structure operating within the current distribution of sovereignty and financial variety across constituencies.

This structural deficit has a direct implication for the Limits to Growth policy debate: calls for "global governance of sustainability" that do not address the variety asymmetry between governance institutions and the industrial-economic system are activity within a stable variety distribution, not genuine variety redistribution. Meaningful governance variety generation would require mechanisms that actually increase the control variety of governance institutions relative to the variety generated by industrial-economic activity, potentially including financial variety transfer from high-variety to governance institutions, technological variety transfer to enable independent monitoring, and institutional variety generation that does not depend on the cooperation of high-variety constituencies whose interests favour the current trajectory.

Power Law Leverage Points

Applying Axioms 39 and 40, the actual situation exhibits power law distributions in the control varieties that matter most for its trajectory. This creates surgical intervention opportunities that the global-aggregate framing of Limits to Growth cannot identify.

Small numbers of critical variety concentrations account for disproportionate control:

- Approximately 100 companies account for the majority of global carbon emissions through their direct operations and product use chains. These entities' variety portfolios, financial, technological, political, are the primary determinants of the emissions trajectory that drives the pollution-climate feedback in the actual situation.
- Approximately 20 nation-states account for 80% of global greenhouse gas emissions. Their collective variety redistribution decisions would determine the atmospheric pollution trajectory more than any number of global agreements.
- A small number of reserve currency nations and international financial institutions control the financial variety allocation that determines investment flows between fossil and non-fossil energy systems.

These power law concentrations create intervention opportunities with a transaction cost logic that Limits to Growth's global aggregate approach cannot identify. Targeting the variety distributions of 100 companies or 20 nations achieves disproportionate impact relative to the transaction costs of comprehensive global governance.

Axiom 37 identifies: "A small number of low-cost, high-impact strategies exist that can achieve maximal change to the locus of power at minimal transaction costs." In the global sustainability situation, these strategies involve targeting the specific variety concentrations, financial allocation, technological capability, institutional rule-setting authority, where small changes in variety distribution produce disproportionate effects on the situation's trajectory.

Discontinuity and the Timing Question

Axiom 48 predicts that as the global situation approaches critical thresholds in resource availability, climate stability, and ecological service provision, the trajectory will exhibit discontinuous rather than smooth transitions. This has governance implications distinct from Limits to Growth's smooth-decline prediction.

A smooth decline trajectory (World3's output) suggests that governance response has time to develop gradually as indicators deteriorate, the multi-decade decline provides time for institutional adaptation. A discontinuous transition trajectory (Axiom 48's prediction for a variety distribution approaching a cusp) provides no such grace period. Critical thresholds crossed produce rapid, potentially irreversible transitions in variety distributions, the kind of cascading failure seen in historical civilisational collapses, without the warning time that smooth decline implies.

The governance implication is that the timing uncertainty problem in World3 may be precisely backwards: not "we have until the 2030s to act before peak food production" but "we face unknown proximity to discontinuous thresholds that, once crossed, produce irreversible transitions faster than governance institutions can respond." This is a different risk structure from what Limits to Growth presents, and it calls for different governance responses, specifically, variety redistribution strategies that reduce the fragility of critical variety concentrations rather than strategies timed to predicted trajectory inflections.

Conclusions

What Variety Dynamics Adds to the Limits to Growth Debate

Variety Dynamics analysis of the Limits to Growth situation is not primarily a critique of World3, it is an identification of the analytical framework appropriate to the subject matter, and an application of that framework to reveal what the appropriate analysis shows.

The central contribution is the *situation/system* distinction and its consequences. The global industrial-ecological-population dynamics is a *situation*, not a *system*. System Dynamics methodology is a *system* applied to a *situation*. This category mismatch means World3 models a hypothetical closed *system* rather than the actual *situation*, and the validation literature, however rigorous, validates the hypothetical *system's* parameterisation rather than the actual *situation's* future behaviour.

Variety Dynamics analysis of the actual situation reveals:

1. **Constituency variety asymmetries** (Axioms 1, 11) that determine whose interests shape the trajectory, invisible to World3's global aggregation
2. **Open boundary dynamics** (Axioms 15, 29, 31) through which geopolitical, financial, and technological variety flows govern the trajectory, excluded by World3's closure assumption

3. **Nyquist-governed delay instability** (Axiom 16) that makes overshoot plausible, but whose timing World3 cannot reliably determine from OECD-biased data
4. **Exponentially scaling transaction costs** (Axioms 34-36) that make the comprehensive technology scenario structurally incoherent as a real-world trajectory
5. **Power law variety control distributions** (Axioms 39, 40) that create surgical intervention opportunities invisible to the global aggregate framing
6. **Discontinuous rather than smooth collapse dynamics** (Axiom 48) that change the risk structure and the governance response required
7. **Structural governance variety deficit** (Axioms 43, 44) that makes current global governance institutions structurally incapable of controlling the situation's variety generation

The Reframing

Limits to Growth asks: will there be collapse, and when? This is a trajectory prediction question presupposing the situation is a system.

Variety Dynamics asks: who controls the variety distributions governing the situation's trajectory, through what mechanisms, and what redistribution strategies exist? This is a structural question appropriate to a hyper-complex situation.

The Variety Dynamics reframing produces governance-relevant answers that the trajectory prediction framework cannot. It identifies specific constituencies, specific variety concentrations, specific leverage points, and specific redistribution mechanisms, intelligence that can inform actual decisions by actual actors in the actual situation. Limits to Growth's trajectory prediction, even if valid for the hypothetical system it actually models, provides limited actionable intelligence because it addresses an object (the hypothetical system) rather than the situation in which governance decisions must be made.

This is not to say that Limits to Growth's warning is wrong. The general finding, that the global situation is in a regime where overshoot dynamics are plausible, that delay structures are long relative to growth rates, and that current trajectories are not sustainable, is consistent with Variety Dynamics analysis and is a genuine and important contribution to understanding. What Variety Dynamics adds is the analytical framework that converts that general warning into specific, actionable intelligence about the locus of control, the mechanisms maintaining it, and the variety redistribution strategies available to those seeking to change it.

Axioms Applied in This Analysis

Axiom 1: Foundational axiom of variety and control, constituency variety asymmetries create structural basis for differential control over the situation's trajectory

Axiom 10: Control via feedback loops, relative control of feedback loops shapes power distribution between constituencies

Axiom 11: Variety, structure hegemony, and distributions of benefits and costs, uneven variety distributions create structural basis for hegemonic control

Axiom 15: Variety Dynamics, reversibility and open boundaries, the global situation has open, not closed, boundaries

Axiom 16: Variety dynamics and Nyquist number, delay structure makes overshoot plausible but timing ungoverned by crude OECD-based parameters

Axiom 17: Variety dynamics and system control, Variety Dynamics operates at meta-functional level, not object-trajectory level

Axiom 25: Variety Dynamics and Information Systems, parameterisation process involves representational loss increasing informatic entropy

Axiom 27: Power and variety as interchangeable resources, financial, political, and technological varieties are mutually convertible

Axiom 29: Variety Dynamics and real-world open networked situations, the global situation operates in open, interconnected networks

Axiom 31: Variety Dynamic Systems: Boundaries, Reversibility and Time, outcomes are not reversible; open boundaries exclude critical dynamics

Axiom 32: Variety Dynamics, Counterfactuals, and Constructors, the actual situation contains variety of possible trajectories; validation compares one against model

Axiom 34: Transaction Cost Limits on Coercive Power, governance variety increase limited by transaction costs

Axiom 35: Transaction Costs Increase with Variety, costs of comprehensive technology deployment increase with variety of interventions required

Axiom 36: Exponential and Combinatorial Transaction Cost Scaling, comprehensive technology scenario transaction costs grow exponentially, not linearly

Axiom 37: Competition Increases Transaction Costs, but low-cost high-impact strategies exist, power law targeting provides high-leverage interventions

Axiom 39: Control effects follow power law distribution, small numbers of constituencies control disproportionate variety

Axiom 40: Variety Dynamics and Power Laws, small proportion of variety distributions account for disproportionate effects on locus of control

Axiom 41: Making Invisible Control Visible, variety manipulation by high-variety constituencies operates beyond two-loop cognitive boundary

Axiom 43: Control Variety in Security Systems, governance institutions must exceed situation's variety to control it; current institutions do not

Axiom 44: Organisational Stability Variety, governance organisations require control variety exceeding environmental, operational, and developmental demands

Axiom 46: Locus of Control Shaped by Time, speed of variety deployment determines effective control; industrial-economic system deploys variety faster than governance institutions

Axiom 48: Discontinuity and Irreversibility, actual situation near thresholds produces discontinuous transitions, not smooth decline

Axiom 49: Defining Simple, Complicated, and Complex Systems, global situation has far more than two feedback loops, requiring formal modelling

Axiom 50: Defining Hyper-Complex Systems, the global situation violates structural stability assumptions required for causal analysis; requires Variety Dynamics approaches focusing on managing locus of control

Axiom 51: Activity within stable variety distributions does not shift power locus, fifty years of global sustainability policy activity has occurred within unchanged variety distributions, explaining its limited effect on the situation's trajectory

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Framework: Variety Dynamics (Love, 2025)