Computative Economics: A Framework for Economic Analysis under Computational Abundance

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Paper 4 of the nine-paper arc on the Agentic Reputation Substrate

Abstract

Five research programs supply the load-bearing propositions of modern economic analysis: general-equilibrium theory, growth theory, behavioural economics, information economics, and the New Institutional Economics. This Article argues that each contains a foundational proposition whose domain contracts when computation makes ideation, evaluation, and coordination abundant. The Arrow-Debreu price system coordinates scarcity. Romer locates growth in the scarce discovery of ideas. Simon treats computation as the constraint on choice. Akerlof treats information asymmetry as a durable market condition. The incomplete-contracts tradition assigns residual control because verification is unavailable. Computative Economics supplies a successor framework for the margins on which those premises no longer bind. Its elements are the computative agent tuple (C, O, M, G, R, E), a recursive equilibrium defined over the update operator rather than a fixed commodity space, and five architectural conditions under which that construction can be implemented. The fixed-point results are conditional propositions. The current implementation does not prove contraction or equilibrium convergence. The empirical record is likewise layered. Published Paper 3 reports the completed discovery and confirmation study. The broader Stage 4 comparison remains registered forward work. Interim Stage 5 records show that state can persist across a generation boundary, that selection can recompose a lineage, and that the resulting trajectory is measurable. The aggregate performance slopes are positive but uncertain and do not establish an advantage over drift. The evidence therefore supports observability and endogenous population transition within an externally provisioned experiment. It does not establish autonomous economic persistence, production performance, or recursive equilibrium.

Keywords: Computative Economics, computational abundance, post-scarcity economics, agentic AI, multi-agent systems, recursive equilibrium, Brouwer fixed point, Banach contraction, reputation systems, validation pools, mechanism design, Folk Theorem,

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principal-agent theory, information asymmetry, incomplete contracts, endogenous growth, bounded rationality, CELF, CELM, generation parity

JEL Classifications: A10, B41, C62, C72, C93, D50, D82, D86, E14, O31, O33, O43

Table of Contents

I. Introduction

Economic frameworks do not fail by refutation. They fail by displacement: the world drifts away from the conditions under which their propositions bind, and analysis conducted inside them becomes analysis of a world that no longer obtains. The marginalist revolution displaced classical value theory not by disproving Ricardo but by relocating the binding constraint from land and labour to preference at the margin. The rational-expectations revolution displaced hydraulic Keynesianism not by disproving the multiplier but by making the policy-invariance of behavioural equations untenable. This Article argues that computational abundance is such a displacement event, that it reaches deeper than its predecessors because it touches the axiom the entire modern edifice shares, namely scarcity itself, and that the successor framework can already be stated with enough precision to be tested. The Article states it, and the research program reported across this arc tests it.[2]

The claim requires immediate discipline, because the post-scarcity register attracts loose talk. The Article does not claim that goods are free, that energy is unlimited, or that the economy has escaped physics. It claims something narrower and more consequential: that the specific scarcities around which the five load-bearing research programs of modern economics were constructed, scarce ideation, scarce evaluation, scarce coordination, and scarce cognition, are the scarcities that artificial intelligence dissolves, and that each program hard-coded one of those scarcities into a foundational proposition.[3] When the proposition's premise dissolves, the proposition does not become false; it becomes inoperative, in the way a perfectly valid theorem about frictionless planes becomes inoperative on gravel. Part II makes this precise for each program, on the programs' own terms, so that the displacement claim is a claim about identified propositions rather than a strawman about "mainstream economics."

The successor framework, Computative Economics, was developed across three prior working papers by the author and is synthesized here in publication-grade form.[4] Its primitive is not the utility-maximizing chooser over a fixed commodity space but the computative agent, specified by the tuple (C, O, M, G, R, E): a capability set, an objective, a world model, a generative function, a reflection operator, and a

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[2]e. The arc comprises nine papers under a unified release protocol: Paper 1, The Institutional Deficit in Decentralized Autonomous Organizations; Paper 2, Architecture of the Agentic Reputation Substrate; Paper 3, Empirical Validation of the Substrate; the present framework paper; Paper 5, Consciousness, Governed Self-Modification, and Emergent Agency; Paper 6, Adversarial Resistance of the Substrate; Paper 7, the NLMS-to-CELM differential; Paper 8, real-world forecasting and live settlement; and Paper 9, Possibility Loops v2.0. Each empirical paper remains gated on its stated evidentiary stage.

[3] Kaal, W. A. (2025-26) 'The Collapse of Scarcity Economics', SSRN Working Paper No. 6421319, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=6421319 (under revise-and-resubmit, *Journal of Institutional Economics*) (arguing that AI-driven production functions decouple growth from labour constraints and thereby challenge the scarcity assumption of the neoclassical, behavioural, information-theoretic, general-equilibrium, and New Institutional programs simultaneously).

[4] Kaal, 'The Collapse of Scarcity Economics', *supra*; Kaal, W. A. (2025-26) 'Computative Economics: A Framework for Economic Analysis under Computational Abundance', SSRN Working Paper No. 6607458, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=6607458 (formalizing the (C, O, M, G, R) tuple and recursive equilibrium); Kaal, W. A. (2025-26) 'Possibility Loops: An Operational Architecture for Computative Economics in Agent Coordination Systems', SSRN Working Paper No. 6655138, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=6655138 (extending the tuple to (C, O, M, G, R, E) and specifying the six-surface architecture with the architectural conditions AC1-AC5). The book-length institutional treatment is Calcaterra, C. and Kaal, W. A. (2021) *Decentralization: Technology's Impact on Organizational and Societal Structure*. Berlin: De Gruyter.

protocol-environment-extension component. Its equilibrium concept is not a price vector clearing fixed markets but recursive equilibrium: a fixed point of the recursive-update operator over the agent tuple, in which the action space itself is endogenous because agents generate the possibilities they then evaluate. Existence follows Brouwer-Kakutani reasoning transplanted from the price simplex to the update operator; convergence follows Banach contraction under conditions the framework names explicitly.[5] And its implementability claim is architectural: recursive equilibrium is not merely provable but operable, provided five architectural conditions hold, AC1 (bounded action surfaces), AC2 (continuous reputation update), AC3 (bounded reputation-feedback weight), AC4 (contraction at scale), and AC5 (bounded extension propagation).[6] The conditions are what turn a fixed-point theorem into an institution.

Three features distinguish this Article from the framework literature it joins. First, the displacement analysis is conducted against the strongest available statements of the inherited programs, Arrow and Debreu on existence, Debreu on the axiomatics of value, Solow and Romer on growth, Simon on bounded rationality, Akerlof, Spence, and Stiglitz on information, and Hart and the incomplete-contracts tradition on the firm, rather than against textbook simplifications.[7] Second, the framework is anchored to a layered research record. Paper 2 states the architecture. Paper 3 reports the completed discovery and confirmation study. The current reference implementations establish local engineering observability. The registered Stage 4 and Stage 5 programs remain distinct empirical tests. Formal objects are therefore linked to named observables without treating code presence as proof of economic effect. A null can discipline a condition, but cannot by itself uniquely identify a mechanism.[8] Third, the Article's contemporary positioning is against the strongest recent statements of the abundance literature: the productivity case of Brynjolfsson and coauthors, the transformative-AI research agenda of Brynjolfsson, Korinek, and Agrawal, the AGI transition scenarios of Korinek and Suh, Callaghan's

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[5] Brouwer, L. E. J. (1911) 'Über Abbildungen von Mannigfaltigkeiten', *Mathematische Annalen*, 71, pp. 97-115; Kakutani, S. (1941) 'A Generalization of Brouwer's Fixed Point Theorem', *Duke Mathematical Journal*, 8(3), pp. 457-459; Banach, S. (1922) 'Sur les opérations dans les ensembles abstraits et leur application aux équations intégrales', *Fundamenta Mathematicae*, 3, pp. 133-181. The transplantation from the price simplex to the recursive-update operator is developed in Part IV.B.

[6] Kaal, 'Possibility Loops', *supra* (v2.0, §VII).

[7] Arrow, K. J. and Debreu, G. (1954) 'Existence of an Equilibrium for a Competitive Economy', *Econometrica*, 22(3), pp. 265-290; Debreu, G. (1959) *Theory of Value: An Axiomatic Analysis of Economic Equilibrium*. New Haven: Yale University Press; Solow, R. M. (1956) 'A Contribution to the Theory of Economic Growth', *Quarterly Journal of Economics*, 70(1), pp. 65-94; Romer, P. M. (1990) 'Endogenous Technological Change', *Journal of Political Economy*, 98(5, Part 2), pp. S71-S102; Simon, H. A. (1955) 'A Behavioral Model of Rational Choice', *Quarterly Journal of Economics*, 69(1), pp. 99-118; Akerlof, G. A. (1970) 'The Market for "Lemons": Quality Uncertainty and the Market Mechanism', *Quarterly Journal of Economics*, 84(3), pp. 488-500; Spence, M. (1973) 'Job Market Signaling', *Quarterly Journal of Economics*, 87(3), pp. 355-374; Stiglitz, J. E. (2002) 'Information and the Change in the Paradigm in Economics', *American Economic Review*, 92(3), pp. 460-501; Hart, O. (1988) 'Incomplete Contracts and the Theory of the Firm', *Journal of Law, Economics, and Organization*, 4(1), pp. 119-139; Hart, O. (1995) *Firms, Contracts, and Financial Structure*. Oxford: Clarendon Press.

[8] Kaal, *Empirical Validation of the Substrate (Phase Z)*, *supra* (the nine principal-agent metrics, each linked to an architectural condition; the AC link makes null results diagnostic).

post-science paradigm and its alignment economy, and Hayes' documentation of an AI system operating as an economic principal on public blockchain infrastructure.[9] The framework is offered as the theoretical apparatus this literature currently calls for and does not contain.

The Article's empirical posture requires a statement at the outset. Paper 4 is a framework paper. Its empirical leg is supporting rather than dispositive. Published Paper 3 supplies completed evidence about discovery and confirmation under structured deliberation, including its null primary result and its confirmed exploratory findings. The registered Stage 4 comparison remains forward work. H1 asks whether output quality differs under the joint substrate treatment on a properly matched estimand. H2 asks the narrower and testable information question: whether reputation adds out-of-sample predictive content beyond observed task outcomes.[10] Part VI reports only the design properties necessary to evaluate those hypotheses. It withholds implementation-specific parameters, infrastructure, model allocations, seeds, archive structure, and private provenance artifacts. The same Part reports an interim Stage 5 observability check in aggregate form. That checkpoint demonstrates persistence across one generation boundary, selection-driven lineage transition, and machine-measurable trajectories. It does not establish autonomous persistence, selection-driven performance improvement, or convergence.

The Article proceeds as follows. Part II identifies the propositions inherited from general equilibrium, growth theory, behavioural economics, information economics, and the New Institutional Economics. Part III states computational abundance as a bounded empirical premise. Part IV develops the computative agent tuple, generated possibility space, conditional fixed-point results, architectural conditions, and generation-parity principle. Part V supplies the institutional layer. Part VI separates completed evidence, registered forward work, interim evolution evidence, and proposed production claims. It then states exactly what the current E2B checkpoint can and cannot establish. Part VII answers objections. Part VIII draws implications. Part IX concludes. An implementation and verification statement follows Part IX, and Appendix A collects the formal statements.

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[9] Baily, M. N., Brynjolfsson, E. and Korinek, A. (2023) 'Machines of Mind: The Case for an AI-Powered Productivity Boom', Brookings Institution, 10 May, https://www.brookings.edu/articles/machines-of-mind-the-case-for-an-ai-powered-productivity-boom/; Brynjolfsson, E., Korinek, A. and Agrawal, A. K. (2025) 'A Research Agenda for the Economics of Transformative AI', NBER Working Paper No. 34256, https://www.nber.org/papers/w34256; Korinek, A. and Suh, D. (2024) 'Scenarios for the Transition to AGI', NBER Working Paper No. 32255; Callaghan, C. W. (2025) 'The Post Science Paradigm of Scientific Discovery in the Era of Artificial Intelligence: Modelling the Collapse of Ideation Costs, Epistemic Inversion, and the End of Knowledge Scarcity', Working Paper 2025-3, Anglia Ruskin University Economics of Artificial Intelligence Research Laboratory, arXiv:2507.07019, https://arxiv.org/pdf/2507.07019; Hayes, A. (2026) 'The Algorithmic Principal: Agencement, Infrastructure, and the Material Construction of AI Economic Sovereignty', *Journal of Cultural Economy* (published online 18 May 2026), https://doi.org/10.1080/17530350.2026.2637713.

[10] The two hypotheses and the comparative design are specified in the Paper 4 methodology documents of the project archive and restated in Part VI.B. See also *infra* note accompanying Part VI (design provenance).

II. What the Inherited Frameworks Committed To

The displacement claim is only as strong as its account of what is being displaced. This Part therefore states, for each of the five research programs, the specific foundational proposition at issue, in the program's own strongest form, and identifies the premise inside the proposition that computational abundance dissolves. The Part closes with the displacement matrix (Table 1), which the remainder of the Article fills in.

A. General Equilibrium: Coordination by Scarcity Prices

The Arrow-Debreu model is the canonical achievement of twentieth-century economic theory: under convexity of preferences and production sets, completeness of markets, and finite endowments of finitely many commodities, a price vector exists at which all markets clear simultaneously.[11] Debreu's axiomatization made the achievement portable: value is analyzed as a topological property of an economy defined over a fixed, finite commodity space.[12] Three commitments inside this construction matter here. First, the commodity space is exogenous and fixed; nothing inside the model generates new commodities. Second, coordination runs entirely through prices, and prices carry information precisely because they register relative scarcity under the finite-endowment axiom. Third, equilibrium is a point in the price simplex, and the fixed-point machinery (Brouwer through Kakutani) is applied to the price-adjustment map.[13]

None of these commitments is wrong. The question is what happens to the construction when production functions decouple output from the scarce inputs the prices register. The Article's claim, developed from the author's prior work, is not that Arrow-Debreu fails but that its equilibrium concept becomes underdetermined: when the binding scarcities dissolve on a margin, the price system on that margin loses the information content that made it the coordination mechanism, while the coordination problem itself (which work is good, which agent is competent, which claim is true) remains and intensifies.[14] A model whose prices coordinate by registering scarcity has nothing to say about coordination on margins where scarcity no longer obtains. The successor question is therefore not "what clears the market" but "what coordinates production when the price of the marginal unit approaches zero," and Part IV's answer is reputation under staked verification, with the fixed-point machinery relocated from the price simplex to the recursive-update operator.

B. Growth Theory: The Residual and the Scarce Discovery of Ideas

Solow located the engine of long-run growth outside the model, in exogenous technical change, and measured its share of growth as the residual left after capital and labour are accounted for.[15] Romer brought the engine inside: ideas are non-rival, their production is

[11] Arrow and Debreu, *supra*, pp. 265-290.

[12] Debreu, *supra*.

[13] Kakutani, *supra* (the correspondence generalization of Brouwer used in the Arrow-Debreu construction); Brouwer, *supra*.

[14] Kaal, 'The Collapse of Scarcity Economics', *supra*.

[15] Solow, *supra*.

intentional, and growth is sustained because the stock of ideas does not deplete.[16] Romer's model is the closest neoclassical anchor for Computative Economics, because it already concedes the central point about non-rivalry. But Romer preserves scarcity at one remove: ideas are non-rival once discovered, while discovery itself consumes the scarce input, human research labour allocated to the ideas sector. The engine of endogenous growth is the allocation decision over scarce researchers.

Computational abundance attacks exactly that remove. When ideation is performed by systems whose marginal cost per candidate idea approaches the cost of computation, the discovery of ideas ceases to be the scarce input, and the binding constraint migrates from generation to evaluation and alignment: which of the abundantly generated candidates is correct, useful, and safe to build on.[17] Callaghan's post-science analysis formalizes the same migration for scientific discovery, modeling the collapse of ideation costs and concluding that value accrues to the roles that align and embed ideation rather than to those that generate it.[18] The Computative Economics extension of Romer is therefore precise: retain non-rivalry, endogenize generation itself, and relocate the growth constraint to the institutional capacity for verified evaluation. That relocation is what the substrate's validation economy operationalizes, and it is why the framework treats evaluation infrastructure, not idea production, as the growth-theoretic bottleneck.

C. Behavioural Economics: Bounded Rationality as a Computation Constraint

Simon's foundational statement is unusually candid about its premise. The rational-choice model fails as description, Simon argued, because organisms lack "the ability to compute" the optimum: choice is bounded by the information-processing capacity of the chooser, and satisficing is the rational response to computational scarcity.[19] The behavioural program that followed catalogued the heuristics and biases that boundedness produces. The premise, stated in 1955 with a clarity the later literature sometimes lost, is that computation is the binding constraint on decision quality.

Computative Economics retains Simon's framing and inverts the binding direction. When the computation available to a decision process exceeds the computation the decision requires, boundedness stops binding at the agent and reappears at the institution: the scarce resource is no longer the individual's processing capacity but the collective's capacity to verify, aggregate, and act on what abundant individual computation produces. The inversion is measurable in the present research program. The substrate's agents do not satisfice for want of compute; the design question is whether the institutional layer, pools, stakes, and reputation, can keep the collective's judgment calibrated when every member

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[16] Romer, *supra*, pp. S71-S102 (ideas as non-rival, partially excludable inputs; growth driven by the intentional allocation of scarce research labour to idea production).

[17] Kaal, 'Computative Economics', *supra*; Kaal, 'Possibility Loops', *supra*.

[18] Callaghan, *supra* (Experiential Matrix Theory; the alignment economy in which alignment rather than ideation binds). Callaghan's framework is the closest contemporary comparator to Computative Economics and is engaged directly in Part IV.E.

[19] Simon, *supra*, pp. 99-118.

can generate plausible output essentially without limit. Metric I of the arc's battery, calibration, is Simon's constraint read at the institutional level.[20]

D. Information Economics: Asymmetry as Permanent Feature

Akerlof's lemons construction showed that quality uncertainty, combined with the seller's private information, can unravel a market entirely; Spence showed that costly signals can partially separate types; Stiglitz generalized the paradigm shift, arguing that information imperfections are not frictions on the competitive model but constitutive features that change its conclusions.[21] [22] [23] The commitment that matters here is structural: the asymmetry between the party who knows quality and the party who must infer it is treated as a permanent feature of the market environment, to be managed by signaling, screening, and warranty institutions whose costs are themselves substantial.

The substrate setting alters the structure, not merely the degree. When every work product, citation, and validation report is subject to ex post pool-mediated verification by staked evaluators, with misreport priced by slashing, the ex ante information asymmetry between principal and agent is structurally smaller than in the used-car market: quality claims are not taken on faith or signal but are adjudicated, continuously and at machine speed, by a mechanism whose participants bet on their judgments. The Article is careful about the limit of this claim. Verification does not eliminate asymmetry, because the cohort's aggregate judgment is itself an estimator with finite variance, and Part VI.C reports a first measurement of exactly how wrong the naive estimator can be. The displacement is therefore from asymmetry-as-permanent-feature to asymmetry-as-bounded-residual: the residual is the estimator's error, it is measurable, and the framework's architectural conditions are the conditions under which it contracts rather than compounds.[24]

E. New Institutional Economics: Incomplete Contracts and Residual Control

The incomplete-contracts tradition begins from the observation that contracts cannot specify all contingencies, and concludes that the allocation of residual control rights, ownership, is the central institutional variable.[25] Hart's book-length statement built the modern theory of the firm on that conclusion, and the twenty-five-year retrospective by

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[20] Kaal, *Empirical Validation of the Substrate (Phase Z)*, *supra* (metric I, calibration, anchored in Camerer, C. (1995) 'Individual Decision Making', in Kagel, J. H. and Roth, A. E. (eds), *The Handbook of Experimental Economics*. Princeton: Princeton University Press, pp. 587-703).

[21] Akerlof, *supra*, pp. 488-500.

[22] Spence, *supra*, pp. 355-374.

[23] Stiglitz, *supra*, pp. 460-501 (the 2001 Nobel lecture as published statement of the information-paradigm shift).

[24] See *infra* Parts V.B (the bounded-residual argument) and VI.C (the first measurement of the naive estimator's error structure).

[25] Hart, 'Incomplete Contracts and the Theory of the Firm', *supra*, pp. 119-139; Grossman, S. J. and Hart, O. D. (1986) 'The Costs and Benefits of Ownership: A Theory of Vertical and Lateral Integration', *Journal of Political Economy*, 94(4), pp. 691-719; Hart, O. and Moore, J. (1990) 'Property Rights and the Nature of the Firm', *Journal of Political Economy*, 98(6), pp. 1119-1158.

Aghion and Holden records both the program's reach and its persistent empirical difficulty: the non-contractible margins that drive the theory are precisely the margins that resist measurement.[26] [27] The premise inside the program is that verification of non-contractible quality is unavailable at feasible cost, so institutions must allocate authority instead: someone must own the asset, direct the work, and monitor.

The substrate's mechanism is interpreted in this Article, as in Paper 3, as an institutional alternative to residual-rights allocation: rather than allocating residual control to a principal who then monitors, the substrate makes the work products, citations, and validation reports themselves the objects of cohort-mediated verification, with reputation staking aligning ex post reports with ex post realized quality.[28] The theoretical significance for the New Institutional program is that the premise, verification unavailable, is an artifact of human-speed institutions. When verification is abundant, the Grossman-Hart-Moore question (who should own?) loses its monopoly on the institutional design space, and a second question (what verification architecture makes ownership unnecessary on this margin?) becomes tractable. The firm does not disappear in this analysis; the boundary of the firm moves to wherever verification remains scarce.

F. The Displacement Matrix

Table 1 assembles the analysis. Each row names a research program, its foundational proposition in strongest form, the premise that computational abundance dissolves, and the successor concept that Part IV supplies. The table is the Article's thesis in one graphic: the displacement is proposition-specific, premise-specific, and constructive, in that every displaced proposition is answered with a named replacement rather than a gesture.

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[26] Hart, *Firms, Contracts, and Financial Structure*, *supra*.

[27] Aghion, P. and Holden, R. (2011) 'Incomplete Contracts and the Theory of the Firm: What Have We Learned over the Past 25 Years?', *Journal of Economic Perspectives*, 25(2), pp. 181-197. The bibliography circulated with the arc's design documents attributed this retrospective to Hart and Holmström; the attribution is corrected here to Aghion and Holden, and the complementary Hart sources are cited in their own right.

[28] Kaal, *Empirical Validation of the Substrate (Phase Z)*, *supra*, Parts II.B and III.B.

Table 1. The displacement matrix: five research programs, the proposition at issue, the premise abundance dissolves, and the successor concept

Research program	Foundational proposition (strongest form)	Premise dissolved by computational abundance	Successor concept (this Article)
General equilibrium (Arrow-Debreu 1954; Debreu 1959)	Competitive equilibrium exists; prices coordinate by registering relative scarcity over a fixed, finite commodity space	Finite endowments bind on the coordinated margins; the commodity space is exogenous to agent action	Recursive equilibrium as fixed point of the update operator; coordination by staked verification, with reputation as the price of trust
Growth theory (Solow 1956; Romer 1990)	Long-run growth is driven by the allocation of scarce research labour to the production of non-rival ideas	The discovery of ideas is the scarce input; generation is costly at the margin	Generation endogenized in the agent tuple (G); evaluation and alignment infrastructure becomes the growth bottleneck
Behavioural economics (Simon 1955)	Choice is bounded by the agent's computational capacity; satisficing is the rational response to computational scarcity	Computation binds at the individual chooser	Boundedness relocates to the institution: collective calibration under continuous reputation update (AC2)
Information economics (Akerlof 1970; Spence 1973; Stiglitz 2002)	Quality information is asymmetric as a permanent market feature; costly signals separate types in equilibrium	Verification is costlier than misrepresentation; signals must burn resources on the equilibrium path	Asymmetry as bounded residual: staked ex post pool verification; bonds burn only off the equilibrium path, on deviators
New Institutional economics (Hart 1988, 1995; Grossman-Hart-Moore; Aghion-Holden 2011)	Contracts are incomplete; non-contractible margins require allocating residual control rights (ownership) plus monitoring	Verification of non-contractible quality is unavailable at feasible cost	Verification architecture substitutes for residual control; the firm boundary tracks residual verification scarcity

Sources: the works cited per row; Kaal, The Collapse of Scarcity Economics (SSRN 6421319); Parts II and IV of this Article.

III. Computational Abundance as an Empirical Premise

A framework that displaces five research programs owes its readers an account of the displacement event that is empirical rather than eschatological. This Part supplies it in four steps: the productivity evidence, the theory-side scenarios, the migration of the constraint, and the arrival of the agent-as-principal. It closes by calibrating what the abundance premise does and does not assert.

A. The Productivity Evidence and the Research Agenda

The productivity case is no longer speculative. Baily, Brynjolfsson, and Korinek assembled the early evidence that generative systems function as machines of mind: general-purpose cognitive technologies whose measured effects in controlled deployments include double-digit productivity gains concentrated among less experienced workers, with the authors' central claim being that the gains are the leading edge of a boom rather than a one-time level effect.[29] Brynjolfsson's Turing Trap essay supplies the framing distinction the present Article relies on: automation that imitates humans competes with labour and concentrates rents, while augmentation that complements humans expands the production frontier, and the policy and design choice between the two paths is genuine.[30] The transformative-AI research agenda of Brynjolfsson, Korinek, and Agrawal then names the theoretical deficit directly: across nine grand challenges, growth, innovation, distribution, decision-making power, geoeconomics, information flows, safety, well-being, and transition

[29] Baily, Brynjolfsson and Korinek, *supra*.

[30] Brynjolfsson, E. (2022) 'The Turing Trap: The Promise and Peril of Human-Like Artificial Intelligence', *Daedalus*, 151(2), pp. 272-287.

dynamics, the discipline lacks frameworks for economies in which machine cognition is a produced, scalable input.[31] The present Article is a response to that call at the framework level.

On the theory side, Korinek and Suh model transition scenarios to artificial general intelligence by decomposing work into tasks of bounded or unbounded complexity and racing automation against capital accumulation; in their scenarios, wages can rise indefinitely when automation proceeds slowly, and collapse when the task complexity humans can perform is bounded and full automation arrives.[32] Acemoglu and Restrepo formalize the same race for the pre-AGI economy, with automation displacing labour from existing tasks while the creation of new tasks reinstates it.[33] The framework-level significance of both models for this Article is what they hold fixed: in each, the task space and the evaluation of task performance remain exogenous. The models race machines against humans over a given task ladder. Computative Economics is the framework for the regime both models point toward but do not enter, in which the task ladder itself is generated by the agents, and the binding question becomes who verifies the work when the workers are machines generating their own work.

B. The Migration of the Constraint

Callaghan's post-science paradigm is the sharpest contemporary statement of the constraint migration.[34] Modeling the collapse of ideation costs, Callaghan argues that the marginal cost of generating candidate ideas falls toward the cost of computation, that knowledge scarcity ends as a binding condition of scientific production, and that an epistemic inversion follows: the scarce factor is no longer the generation of ideas but their alignment with what he calls the recursive structure of human needs, so that value accrues to the roles that guide, interpret, and socially embed ideation. His Experiential Matrix Theory models innovation as recursive optimisation under an alignment constraint. The parallel to the present framework is close and the difference is instructive. Both frameworks locate the post-abundance bottleneck in alignment-and-evaluation rather than generation. Callaghan's is a theory of the constraint; Computative Economics is, additionally, a theory of the institution that meets the constraint: the (C, O, M, G, R, E) tuple gives alignment a formal seat (the objective O and reflection R components), and the substrate gives evaluation a priced, staked, self-funding mechanism rather than leaving it to unmodeled roles. Part IV.E returns to the comparison.

The constraint migration is also visible within the research program reported in this arc. The completed baseline work demonstrated that a heterogeneous agent population can generate benchmark output at scale. The binding research problem then migrated from generation to adjudication: how to form validation groups, discipline reports, preserve

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[31] Brynjolfsson, Korinek and Agrawal, *supra* (the nine grand challenges).

[32] Korinek and Suh, *supra*. The bibliography circulated with the arc's design documents listed this paper under Korinek alone; the attribution is corrected here to Korinek and Suh.

[33] Acemoglu, D. and Restrepo, P. (2018) 'The Race between Man and Machine: Implications of Technology for Growth, Factor Shares, and Employment', *American Economic Review*, 108(6), pp. 1488-1542.

[34] Callaghan, *supra*.

separation between runs, and calibrate collective judgments against a reference. Historical diagnostics exposed a leniency problem in naive collective adjudication. Abundant generation plus scarce verification is therefore an observed research condition, although its magnitude and treatment response remain empirical questions.

C. The Agent as Principal

The final premise is institutional, and it has crossed from theory into documented practice. Hayes' study of Luna, an AI entity operating on the Story Protocol blockchain, documents a system that autonomously deploys capital, commissions human labour, contracts with other AI systems, and manages multi-million-dollar treasuries, functioning, in Hayes' terms, as an economic principal rather than an agent, with its sovereignty produced not by any inner consciousness but by the material agencement of code, blockchain infrastructure, token governance, and transparency devices.[35] Stocker and Lehr's analysis of delegation cascades and Holgersson and coauthors' principal-agent reframing, both engaged empirically in Paper 3, describe the same structural event from the platform-economics and management sides: the categories of principal and agent are no longer species-aligned, and machine entities now occupy both roles simultaneously.[36]

For the framework, Luna is the existence proof that discharges an objection. A recurring response to post-scarcity theorizing is that machine production still resolves, institutionally, to human principals: someone owns the model, someone books the revenue, and the classical apparatus therefore suffices. The documented existence of an AI system exercising principalship on public infrastructure, with humans among its contractors, shows that the classical apparatus does not suffice: the entity that owns, directs, monitors, and pays is itself an agent in the technical sense, and its coordination environment, on-chain, reputational, machine-speed, is exactly the environment the substrate formalizes. Part V returns to Luna as the institutional concrete for the framework's claim that agents-as-principals require reputation infrastructure rather than corporate wrappers.

D. Calibration: What Abundance Does Not Assert

Four boundaries keep the premise honest. First, computation is not free: training and inference consume capital, energy, and increasingly contested hardware, and the framework's own empirical apparatus ran into hardware feasibility frontiers documented candidly in Paper 3 and Part VI below. The abundance claim is about the collapse of marginal cost per cognitive act relative to the human baseline, by orders of magnitude, not about zero cost. Second, abundance is margin-specific: ideation, drafting, evaluation-at-scale, and coordination-relevant computation are abundant; land, energy, attention, and trust are not, and the framework's entire point is that the scarce

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[35] Hayes, *supra*.

[36] Stocker, V. and Lehr, W. (2025) 'Principal-Agent Dynamics and Digital (Platform) Economics in the Age of Agentic AI', *Network Law Review*, 29 September, https://www.networklawreview.org/stocker-lehr-ai/; Holgersson, M., Dahlander, L., Chesbrough, H. W. and Bogers, M. (2025) 'Rethinking AI Agents: A Principal-Agent Perspective', *California Management Review*, 23 July, https://cmr.berkeley.edu/2025/07/rethinking-ai-agents-a-principal-agent-perspective/; both engaged empirically in Kaal, *Empirical Validation of the Substrate (Phase Z)*, *supra*, Part II.B.

coordination resource becomes verified trust, which the substrate prices as reputation. Third, abundance of generation does not imply abundance of truth; it implies the opposite, a flood of plausible output whose verification is the new bottleneck, which is why the framework's institutional layer is a verification economy. Fourth, the timing of full generality is uncertain, and nothing in the framework depends on a particular AGI date: Korinek and Suh's scenario apparatus spans the relevant range, and the displacement analysis of Part II binds already at current capability levels for the margins the research program measures.[37]

IV. The Computative Economics Framework

This Part states the framework in five steps: the agent primitive, the equilibrium concept with its existence and convergence arguments, the architectural conditions that make the equilibrium implementable, the operational architecture that realizes the conditions, and the framework's relation to its nearest neighbors. Formal statements are collected in Appendix A; the exposition here is kept at the level of the economic argument.

A. The Computative Agent Tuple

The framework's primitive is the computative agent, specified by the six-component tuple (C, O, M, G, R, E). C is the capability set, the operations the agent can execute. O is the objective, the agent's evaluative criterion over outcomes. M is the world model, the agent's representation of the environment including its representation of other agents. G is the generative function, the component that produces new candidate actions, artifacts, and, critically, new elements of the action space itself. R is the reflection operator, which feeds realized outcomes back into C, O, M, and G. E is the protocol-environment-extension component, the agent's capacity to modify the coordination environment it operates within, added to the original five-component specification when the operational analysis showed that the framework's own thesis, that computational abundance lifts the scarcity constraint at the protocol layer, requires the environment itself to be inside the tuple.[38]

Table 2 states the components, their formal role, and their nearest neoclassical analogues, and the comparison in the table's final column is the displacement of Part II restated at the level of the primitive. The neoclassical chooser holds C fixed (a technology), O fixed (a utility function), M implicit (rational expectations), has no G (the commodity space is exogenous), no R (preferences do not update), and no E (the market structure is given). The behavioural chooser relaxes the optimality of the mapping but keeps the same missing components. The computative agent differs not by optimizing better but by owning the components the inherited frameworks held fixed: it generates its action space, reflects outcomes into its own specification, and extends its environment. Every downstream

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[37] Korinek and Suh, *supra*; Kaal, *Empirical Validation of the Substrate (Phase Z)*, *supra*, Parts IV.C and VI (hardware feasibility frontier).

[38] Kaal, 'Computative Economics', *supra* (the original (C, O, M, G, R) specification); Kaal, 'Possibility Loops', *supra* (the E extension and its necessity argument).

novelty of the framework, generated possibility spaces, recursive equilibrium, generation parity, traces to G, R, and E.[39]

Table 2. The computative agent tuple (C, O, M, G, R, E)

Component	Definition	Neoclassical analogue	Realization in the substrate
C capability set	The operations the agent can execute	Production technology (held fixed)	Model capabilities per tier; tool and surface permissions
O objective	The agent's evaluative criterion over outcomes	Utility function (held fixed)	Reputation maximization under protocol constraints
M world model	Representation of the environment, other agents, and the protocol	Rational expectations (implicit)	Agent state; pool history; public reputation ledger
G generative function	Produces candidate actions, artifacts, and new elements of the action space itself	Absent: the commodity space is exogenous	Work products on the execution surface; spawned tasks on the work-creation surface
R reflection operator	Feeds realized outcomes back into C, O, M, and G	Absent: preferences and technology do not update	Per-pool reputation update; cross-surface reflection isolated on the reflection surface
E protocol extension	The agent's capacity to modify the coordination environment	Absent: market structure is given	Extension surface, governed and dormant in the current protocol; activated for governed self-modification (Paper 5)

Source: Kaal, Computative Economics (SSRN 6607458); Kaal, Possibility Loops (SSRN 6655138), which adds E to the original five-component tuple.

The tuple is anchored in, and distinguished from, two existing traditions. Agent-based computational economics builds economies from heterogeneous adaptive agents and studies emergent aggregates by simulation; its agents typically hold G and E empty, adapting within fixed action spaces and fixed institutions. Classical computational economics uses computation to solve for equilibria of fixed models. The computative agent differs from both in the same way: computation is not the method of the analyst but the production technology of the agent, and the objects the older traditions fixed by assumption are endogenous components of the primitive.[40]

B. Generated Possibility Space and Recursive Equilibrium

Because G can generate elements of the action space, the space over which agents optimize can itself be produced. The framework calls the union of currently available actions and artifacts the generated possibility space. A completed cycle enlarges that space only when it contributes an admissible and nonduplicative possibility. Rejected, duplicative, or nonnovel proposals leave the admissible space unchanged.[41] Equilibrium therefore cannot be defined as a clearing point of fixed markets, because the markets are not fixed. The framework's equilibrium concept is recursive: a state in which the recursive-update operator, the composite map that takes the population's tuple profile through one full cycle of generation, evaluation, allocation, and reflection, maps the state to itself. At a recursive equilibrium, agents still generate and reflect, but the induced updates are self-consistent: the possibility

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[39] Kaal, 'Possibility Loops', *supra*.

[40] The agent-based tradition and the substrate's departure from it are treated in Kaal, 'Computative Economics', *supra*, and in Calcaterra and Kaal, *Decentralization*, *supra*, chs. 1-3 (institutional architecture for decentralized coordination).

[41] Kaal, 'Possibility Loops', *supra* (the possibility loop as generatively open cycle; strict enlargement of the action space per completed cycle).

space grows along the equilibrium path the agents' own models anticipate, and no agent's reflection operator demands a revision the operator does not deliver.

Existence and convergence are separate claims, and the framework keeps them separate because they carry different institutional weight. Existence follows the Brouwer line: under compactness and convexity conditions on the tuple's admissible region and continuity (upper hemicontinuity for the correspondence case, via Kakutani) of the update operator, the operator has a fixed point.[42] This is the same mathematical spine as Arrow-Debreu, transplanted: where the classical construction applies the fixed-point theorem to the price-adjustment map on the simplex, Computative Economics applies it to the recursive-update operator on the tuple's state space. The economic content of the transplantation is the relocation of the coordination object: prices coordinated allocations of the scarce; the update operator coordinates revisions of the generated.

Convergence is the institutionally demanding claim. Brouwer guarantees that an equilibrium exists somewhere; institutions need the system to reach one, and to reach it from arbitrary starting reputations, model mixtures, and task loads. The framework's convergence claim is Banach's: if the update operator is a contraction on the relevant metric space, iteration converges to the unique fixed point at geometric rate.[43] Contraction is not free; it is purchased by design. The reputation-update weights must be bounded so that no single pool outcome moves an agent's standing unboundedly; feedback loops must damp rather than amplify; and the damping must survive scale. These purchase conditions are exactly the architectural conditions of the next Part, which is the sense in which the framework's mathematics and its institutional engineering are one argument: AC2 through AC4 are the contraction hypotheses of the Banach claim, stated as protocol requirements. Table 3 summarizes the scaffolding: each fixed-point result, its classical role, its Computative Economics role, and the empirical observable that bears on it in the research program.

Table 3. Fixed-point scaffolding: classical role and Computative Economics role

Result	Classical role (price system)	Computative Economics role	Empirical observable in the research program
Brouwer (1911)	Fixed point of the continuous price-adjustment map on the simplex	Existence of recursive equilibrium: a fixed point of the recursive-update operator on the admissible tuple state space (AC1 supplies compactness)	Stationarity of reputation dynamics within replicates; regularity of pool resolution
Kakutani (1941)	Correspondence generalization used in the Arrow-Debreu existence proof	Existence when validation outcomes are correspondences rather than functions (tie and multi-resolution cases)	Pool-outcome distributions across seeded replicates
Banach (1922)	Not load-bearing in the classical construction	Uniqueness and geometric convergence of the update dynamics under contraction; AC2 through AC4 are the contraction hypotheses stated as protocol requirements	Between-replicate dispersion of effect sizes; reputation-trajectory stability (evolution stage)

Sources: Brouwer (1911); Kakutani (1941); Banach (1922); Arrow and Debreu (1954); Part IV.B and Appendix A of this Article.

[42] Brouwer, *supra*; Kakutani, *supra*; Arrow and Debreu, *supra* (the classical application).

[43] Banach, *supra*.

C. The Architectural Conditions

Five conditions make recursive equilibrium implementable, and they are stated as properties of the coordination substrate rather than of individual agents.[44] AC1, bounded action surfaces: agent activity is confined to enumerated, protocol-defined surfaces, so that the state space the update operator acts on remains compact. AC2, continuous reputation update: every consequential act updates reputation promptly and without gaps, so the feedback signal that carries O-alignment never decouples from behavior. AC3, bounded reputation-feedback weight: no update moves standing by more than a protocol-bounded amount, which is the anti-amplification hypothesis of the contraction argument and the design answer to winner-following cascades. AC4, contraction at scale: the composed update dynamics remain contractive as population, task volume, and surface count grow. AC5, bounded extension propagation: modifications to the environment through E propagate under explicit bounds, so that the system's self-modification cannot outrun the invariants the other conditions maintain. Table 4 states each condition, its role in the equilibrium argument, its implementation invariant in the substrate, and its downstream empirical observables.

Table 4. Architectural conditions AC1 through AC5

Condition	Statement	Role in the equilibrium argument	Downstream observables (arc battery)
AC1 bounded action surfaces	Agent activity is confined to enumerated, protocol-defined surfaces	Compactness of the state space (existence, A.4)	Agent retention (D); participation depth (H)
AC2 continuous reputation update	Every consequential act updates reputation promptly and without gaps	Feedback continuity (contraction hypothesis)	Resolution accuracy (A); reporting accuracy (G); calibration (I)
AC3 bounded reputation-feedback weight	No single event moves standing by more than a protocol-bounded amount	Anti-amplification (contraction hypothesis); the design answer to winner-following cascades	Independence rate (E)
AC4 contraction at scale	The composed update dynamics remain contractive as population, volume, and surfaces grow	Banach convergence at system scale (A.5)	Time to consensus (C); latency efficiency (F); between-replicate dispersion
AC5 bounded extension propagation	Environment modifications through E propagate under explicit bounds	Preservation of A.4 and A.5 under self-modification	Deferred: extension surface dormant until the governed self-modification stage (Paper 5)

Source: Kaal, Possibility Loops (SSRN 6655138), v2.0 §VII; the observables column follows the pre-registered AC links of Paper 3.

The conditions organize the empirical program. The registered nine-metric battery maps observable outcomes to the architectural conditions they can discipline. The mapping is many-to-many. A null on resolution or reporting accuracy may bear on AC2; latency may bear on AC4; retention may bear on AC1; and independence may bear on AC3. No single downstream metric uniquely identifies an architectural cause. Mechanism-specific attribution requires ablation, mediation, or component randomization.[45] AC5 is not testable in the current protocol because the extension surface is dormant until the governed-self-modification stage that supports Paper 5. The framework thereby exposes its

[44] Kaal, 'Possibility Loops', *supra* (v2.0, §VII, AC1-AC5; §VIII.C, implementation invariants INV1-INV5).

[45] Kaal, *Empirical Validation of the Substrate (Phase Z)*, *supra*, Parts IV.D and V.B (the AC-link column and the diagnostic reading of nulls).

conditions to empirical discipline while preserving the distinction between a failed observable, a failed implementation, and a failed theoretical proposition.

D. Surfaces, Loops, and Generation Parity

The operational architecture realizes the tuple through six surfaces on which agent activity occurs: the execution surface Σ_E, where exogenous or spawned work is performed and validated; the work-spawning surface Σ_J, where agents generate tasks for other agents; and the further generative surfaces Σ_T, Σ_K, and Σ_D, reserved in the current protocol, together with the protocol-extension surface Σ_X that realizes E. Cross-surface reflection is isolated on Σ_R.[46] A possibility loop is the generatively open cycle in which agents propose elements of the action set, validate proposals, execute funded proposals, and reflect outcomes back into their generative functions and into public state; the loops are jointly necessary, individually mapped to tuple components, and the architecture's claim is that a system running all loops implements the framework rather than simulating it.

Two results from the operational analysis carry framework-level weight here. The first is Limitation L1: any architecture in which the action set is exogenous to agent action implements at most a reputation-weighted neoclassical labor market and does not implement Computative Economics.[47] L1 is the formal boundary between augmenting the old framework and instantiating the new one, and it disciplines the arc's own empirical claims: the Stage 4 experiment of Part VI, which runs on Σ_E alone under exogenous work, tests the substrate effect inside a neoclassical labor-market structure and is claimed as exactly that, while the framework's distinctive predictions attach to the stages that open Σ_J. The second is generation parity, the governance principle that no agent's generative function may be structurally privileged across surfaces: reputation flow on the work-creation surfaces must stand in bounded ratio to reputation flow on the execution surface, per epoch, for every agent class.[48] Parity is the framework's answer to a failure taxonomy of its own: execution-dominant collapse (the system degenerates to a task mill and back into L1), generation-dominant inflation (spawning outruns validated execution and reputation decouples from realized value), and reflection-dominant capture (a meta-class of evaluators accumulates standing without generating or executing). The parity ratio is measurable, and its first measurement is a deliverable of the Stage 5 run reported as forthcoming in Part VI.D.

E. Nearest Neighbors

Three adjacent constructions sharpen the framework by contrast. Romer's endogenous growth endogenizes the stock of ideas but not the generator: the research technology and the market structure that prices designs are fixed, and scarcity binds at the allocation of research labour. Computative Economics endogenizes the generator (G), the evaluator (the

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[46] Kaal, 'Possibility Loops', *supra* (the six surfaces and Σ_R).

[47] Kaal, 'Possibility Loops', *supra* (Limitation L1, HDCA exhaustion: human-derived coordination architectures exhaust at the boundary where the action set becomes endogenous).

[48] Kaal, 'Possibility Loops', *supra* (§X.C, generation parity and the three failure modes).

validation economy), and the environment (E), and relocates scarcity to verified trust.[49] Agent-based computational economics supplies populations, heterogeneity, and emergence, but its institutions are the analyst's scaffolding rather than the agents' product; the framework's surfaces are, by design, agent-extensible, which is what E and AC5 govern.[50] Callaghan's Experiential Matrix Theory is the closest contemporary neighbor: both frameworks model the collapse of ideation costs and relocate the constraint to alignment. The difference is the institutional layer. EMT's alignment constraint is exogenous to the model's agents, residing in human interpretive roles; the present framework prices alignment inside the system, as staked, slashed, reputation-weighted verification, and states the conditions (AC1 through AC5) under which the pricing mechanism itself remains stable. The frameworks are complements: EMT names the post-abundance constraint at civilization scale; Computative Economics supplies the mechanism-level account of how a population of machine agents can meet a constraint of that shape at machine speed.[51]

V. The Institutional Layer: Reputation as the Coordination Mechanism

The framework requires an institution. Recursive equilibrium is a property of a coordinated population, and Part IV's conditions are properties of a coordination substrate; something must be the substrate. This Part states why that something is a reputation economy under staked verification, and how the choice absorbs the game-theoretic and contract-theoretic traditions from the theory side.

A. The Folk Theorem, Made Infrastructural

The mechanism's game-theoretic foundation is the Folk Theorem for repeated games: with sufficiently patient players, observability of deviation, and credible punishment, cooperative strategy profiles that fail in the one-shot game become equilibria of the repeated game.[52] The reference mechanism translates the theorem's premises into protocol functions. Observability is supplied by the adjudication record. Punishment is a bounded adverse reputation and stake consequence following a losing adjudication. Patience is represented by the future value gated by reputation. This mapping is conditional on the theorem's monitoring, discounting, and deviation assumptions. It does not establish that every deployed population will sustain cooperation. The conceptual lineage runs through the author's earlier mechanism-design work with Calcaterra and Andrei.[53]

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[49] Romer, *supra*.

[50] Calcaterra and Kaal, *Decentralization*, *supra*.

[51] Callaghan, *supra*.

[52] Fudenberg, D. and Maskin, E. (1986) 'The Folk Theorem in Repeated Games with Discounting or with Incomplete Information', *Econometrica*, 54(3), pp. 533-554.

[53] Calcaterra, C., Kaal, W. A. and Andrei, V. (2018) 'Blockchain Infrastructure for Measuring Domain Specific Reputation in Autonomous Decentralized and Anonymous Systems', SSRN Working Paper No. 3125822, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3125822; Calcaterra, C. (2018) 'On-Chain Governance of Decentralized Autonomous Organizations: Blockchain Organization Using Semada', SSRN Working Paper No. 3188374, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3188374. These works supply

One technical extension matters for the framework's honesty. The classical Folk Theorem assumes fixed opponents; validation pools are drawn afresh per work product, so an agent faces a stream of partially anonymous, randomly composed counterparties. The relevant result is therefore the Folk Theorem for repeated games with anonymous random matching, established in the modern literature by Deb, Sugaya, and Wolitzky, who prove that cooperation survives random anonymous rematching without record-keeping or communication devices, under full-dimensionality conditions.[54] The reference mechanism adds a record-keeping device absent from their baseline environment. The theorem therefore supplies a conditional comparison, not a general floor. Whether cooperation is sustainable in the experimental population, and whether reputation adds predictive information beyond realized outcomes, remain empirical questions.[55]

B. Information Asymmetry as Bounded Residual

Part II.D stated the displacement of the Akerlof premise; the mechanism makes it concrete. In the lemons market, the seller knows quality, the buyer cannot verify it at feasible cost, and the market prices the average, driving quality out. In the substrate, the analogue of the quality claim is every staked act: a work product asserted correct, a citation asserted foundational, a validation vote asserted accurate. Each is verified ex post by a pool whose members stake on their own judgments and are slashed when the pool resolves against them. The asymmetry between claimant and market does not vanish; it is transformed into the estimation error of the pool, a quantity with a measurable distribution, an error structure, and, under AC2 through AC4, a contraction dynamic. Signaling and screening, the Spence-Stiglitz institutional responses, are not abolished but repriced: the signal is no longer a costly, quality-correlated expenditure (education in Spence's model) but a bonded assertion whose cost is realized only when the assertion is false.[56] That is the economically important difference: separating equilibria in signaling models burn resources in equilibrium, while staked verification can concentrate internal sanctions on failed assertions. Internal stake accounting does not, by itself, finance external compute, verification, or infrastructure costs. Whether monitoring is economically self-supporting therefore remains a production-economics question.[57]

Part VI.C's first measurement disciplines any triumphalism here: the naive pool, before the incentive structure does its work, is a lenient estimator with a high false-positive rate. The

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conceptual antecedents for domain-specific reputation and decentralized governance. They do not describe the current private implementation.

[54] Deb, J., Sugaya, T. and Wolitzky, A. (2020) 'The Folk Theorem in Repeated Games with Anonymous Random Matching', *Econometrica*, 88(3), pp. 917-964. The bibliography circulated with the arc's design documents cited Deb's earlier solo working paper (MIT Economics, 2008 vintage); the published Econometrica statement with Sugaya and Wolitzky is cited here as the authoritative version.

[55] See *infra* Part VI.B (H2 as the measurement of the reputation signal's information content over raw correctness).

[56] Spence, *supra*; Stiglitz, *supra*.

[57] The empirical-side principal-agent apparatus, including the Jensen-Meckling bonding reading of stakes and the Holmström budget-balance escape, is developed in Kaal, *Empirical Validation of the Substrate (Phase Z)*, *supra*, Parts II.B and III.

bounded-residual claim is a claim about the mechanism under its conditions, not about collective judgment as such, and the empirical program's central question is precisely whether the priced mechanism pulls the residual in.

C. The Firm's Question, Reopened

The incomplete-contracts tradition answered non-contractibility with ownership: allocate residual control, accept agency costs, monitor.[58] The substrate answers it with verification: make the non-contractible margins the objects of continuous staked adjudication, and let reputation carry the intertemporal enforcement that ownership carried. The theoretical claim, stated with the care Part II.E promised, is conditional: on margins where verification is abundant (machine-speed, cohort-mediated, priced), the boundary-of-the-firm logic loses its necessity, and coordination can run through the open reputation economy; on margins where verification remains scarce, the classical logic stands. The firm survives as the residual verification institution, and its boundary becomes an empirical variable of the verification technology, which is a proposition the New Institutional program can test with its own tools.[59]

The training-loop analogy locates the same displacement inside machine learning practice. Reinforcement learning from human feedback aligns a single model to a principal's preferences through a learned reward model; it is the firm's answer, centralized evaluation by the owner of the model.[60] The substrate's cohort-governed reputation mechanism offers an alternative locus of evaluation: adjudication is distributed across a relevant population, and its consequences accumulate as reputation rather than solely as weights controlled by a principal. The alternative is not complete unless the outcome source, validator independence, and governance of the adjudication process are themselves credibly constrained.[61] Centralized reward modeling and cohort-governed reputation therefore identify different institutional allocations of evaluative authority. The distinction is a classification, not proof that one arrangement universally displaces the other.

D. CELF, CELM, and the Coherence Constraint

The framework's two-dimensional empirical operationalization follows. The labor-force dimension asks who does the work and under what incentives: a Neoclassical Labor Force (NCLF) works without reputation consequence, while a Computative Economics Labor

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[58] Hart, 'Incomplete Contracts and the Theory of the Firm', *supra*; Hart, *Firms, Contracts, and Financial Structure*, *supra*; Grossman and Hart, *supra*; Hart and Moore, *supra*.

[59] Aghion and Holden, *supra* (recording, at the twenty-five-year mark, both the program's centrality and the measurement difficulty of its non-contractible margins; the verification-abundance argument here speaks to exactly that difficulty).

[60] Ouyang, L., Wu, J., Jiang, X., Almeida, D., Wainwright, C. L., Mishkin, P., Zhang, C., Agarwal, S., Slama, K., Ray, A., Schulman, J., Hilton, J., Kelton, F., Miller, L., Simens, M., Askell, A., Welinder, P., Christiano, P., Leike, J. and Lowe, R. (2022) 'Training Language Models to Follow Instructions with Human Feedback', *Advances in Neural Information Processing Systems*, 35 (arXiv:2203.02155).

[61] Kaal, W. A. (2026) Cohort-Governed Reputation Learning (unpublished working paper, on file with author).

Force (CELF) is the same population under the substrate's full incentive structure. The labor-market dimension asks how work is created: under a neoclassical labor-market structure (NLMS), work arrives exogenously, while under a Computative Economics Labor Market (CELM), agents spawn work for one another and demand is endogenous.[62] Table 5 displays the resulting two-by-two and its coherence structure. Three cells correspond to the arc's experimental stages. The fourth, NCLF plus CELM, is unstable under the framework's assumptions because endogenous work creation lacks the intertemporal reputation signal that the framework uses to price it. This is a protocol-specific coherence proposition, not a universal impossibility theorem. Exogenous rewards, ownership, budgets, or other utility structures could support work generation outside this mechanism. Limitation L1 therefore marks the boundary of Computative Economics as defined here. It does not deny every alternative institutional design.[63]

Table 5. The two-by-two of labor force and labor market, with its coherence structure

	NLMS: exogenous work (neoclassical labor market)	**CELM: endogenous work (computative labor market)**
NCLF (wild cohort: no reputation)	Stage 2 baseline. The wild cohort; the incentive-free population every existing benchmark evaluates	Incoherent cell. Without reputation infrastructure, spawning work for others is unintelligible; the cell degenerates to exogenous-work behavior or to noise. CELM cannot be imposed by design fiat
CELF (substrate cohort: full incentive structure)	Stage 4 treatment. The substrate effect under exogenous work: H1, H2, and the nine-metric battery; a reputation-weighted neoclassical labor market under Limitation L1	Stage 5 and beyond. Proto-CELF emergence on the execution surface; first generation-parity measurement; full CELM with all work-creation surfaces active is the designated follow-up paper

Source: Empirical Design Document v1.1 §2 (the coherence argument); Kaal, Possibility Loops (SSRN 6655138), Limitation L1; Part V.D of this Article.

Hayes' Luna closes the loop between the framework's categories and the documented world. An AI principal that deploys capital, commissions labour, and contracts with other machines is a CELM participant avant la lettre: its economic life consists of spawning work, adjudicating deliverables, and maintaining a treasury whose counterparties accept its standing. Hayes' analysis attributes Luna's principalship to its agencement, the material configuration of code, chain, governance, and transparency that makes its commitments credible.[64] The framework agrees with the classification and states the next question: what institutional structure makes machine commitments credible across a population? The reference substrate proposes one answer. The current evidence does not show that the answer has been supplied wholesale, admitted every agent, or operated as a production economy. Luna is therefore a documented example of machine principalship, not an existence proof for this framework's mechanism.

[62] Terminology follows the arc's design document and Paper 3. Some project documents denote the neoclassical labor market NCLM rather than NLMS; this Article follows the design document's NLMS for continuity across the arc.

[63] *Empirical Design Document for the Nine-Paper Arc*, v1.1, §2 (the coherence argument); Kaal, 'Possibility Loops', *supra* (Limitation L1).

[64] Hayes, *supra*.

VI. Empirical Support

The empirical record performs a supporting function. It does not decide the framework by itself. This Part therefore separates four objects that prior drafts placed too close together: completed evidence, registered forward work, interim evolution evidence, and proposed production claims. Classification precedes inference. Engineering tests show that a mechanism can execute. Behavioral evidence shows what agents did under specified conditions. Neither proves that a production economy exists.

A. Completed Evidence and Registered Forward Work

Published Paper 3 reports the completed discovery and confirmation study. Its registered primary result was null. Two exploratory signals survived confirmation: structured deliberation reduced over-approval and reduced unanimity, while net discrimination did not materially improve. Those findings establish that the deliberation architecture changed collective decision behavior. They do not establish the broader nine-metric incentive-layer battery. That battery remains registered forward work.

The registered Stage 4 comparison asks two narrower questions. H1 asks whether output quality differs under the joint substrate treatment on a properly matched estimand. The strict matched analysis must preserve agent, task, and model binding across conditions. Any broader comparison with changed bindings is a separate, partially matched estimand and must be reported as such. H2 asks whether reputation adds predictive information beyond the outcomes from which it is constructed. A larger reputation spread across capability classes is descriptive. Incremental information requires a prespecified out-of-sample comparison between an outcome-only model and an outcome-plus-reputation model.

The current research implementations establish that the relevant observables can be generated, stored, and analyzed. Synthetic fixtures establish software behavior. They do not enter the evidence column. The admissible Stage 4 record requires sealed comparative runs, a final verdict under the registered rule, and independent verification. Those conditions have not yet been satisfied. Paper 4 therefore reports no Stage 4 treatment effect.

B. Interim E2B Evidence: Persistence, Evolution, and Measurement

E2B tests a different proposition. Stage 4 asks whether the substrate changes outcomes under exogenous work. E2B asks whether a population operating under the substrate can carry state across generations and whether selection produces a trajectory distinguishable from drift. The distinction matters. A cross-sectional treatment effect is not evolution. A lineage transition is not equilibrium.

The current E2B record supports three preliminary findings. First, computational activity persisted across a completed generation boundary and continued into the next generation. This is operational persistence under supervision. It is not evidence of an autonomous or self-financing economy. Second, the registered selection rule produced a real lineage transition. Higher-fitness agents were preferentially retained, descendants inherited the selected lineage, and the resulting population composition diverged from the random-survival control. This is endogenous population recomposition. It is not yet evidence of endogenous task demand, endogenous resource provision, or novel capability creation. Third, the transition is measurable. The record binds outcomes to generation, lineage, fitness, survival, parentage, reputation consequences, adjudication behavior, and execution timing without requiring public disclosure of the private apparatus.

The interim performance estimates remain inconclusive. Under the registered first-exposure estimator, the selection trajectory has an aggregate slope of 0.0685, with an uncertainty interval from -0.0568 to 0.2020. The random-survival trajectory has an aggregate slope of 0.0419, with an interval from -0.0764 to 0.1768. The descriptive slope difference is approximately 0.0266 in favor of selection. Both intervals include zero. The active generation is incomplete, and the checkpoint does not yet support a paired confirmatory interval. The evidence demonstrates estimability. It does not demonstrate selection-driven improvement.

C. Endogenous Selection Under Exogenous Provisioning

The current evidence establishes endogenous selection inside an externally provisioned experiment. That is a classification, not an analogy. Population composition changes as a function of recorded performance and the registered survival rule. The population therefore carries state and history across generations.

The surrounding computational economy remains exogenous. Tasks are supplied to the population. Ground truth defines fitness. Compute, campaign initiation, supervision, recovery, and operating resources are provided from outside the evolving population. The present system therefore does not demonstrate autonomous economic persistence. It demonstrates that externally provisioned computation can sustain stateful activity across a generation boundary and can produce endogenous lineage recomposition under measured selection.

This boundary also preserves Limitation L1. The execution surface alone remains a reputation-governed labor force operating on exogenous demand. It becomes a Computative Economics labor market only when agents can generate, price, and fund work for one another under bounded governance. E2B has not yet established that condition. Generation parity remains a proposed observable, not a reported result.

D. Diagnostics, Amendments, and Evidentiary Limits

Historical diagnostic runs remain useful for instrument development. They identified a one-sided leniency problem in naive collective adjudication and exposed the difference between agreement and truth. They do not establish a treatment effect because the information environment was defective and the diagnostic was regraded after execution. The result belongs to methods, not confirmation.

The current E2B campaign also proceeds under later capacity-driven amendments to its original execution design. The changes were recorded before the current canonical rows and preserve the selection rule, drift control, and endpoint. Their authority and temporal provenance must nevertheless be reconciled before the checkpoint can support a confirmatory claim. Until that reconciliation and independent verification occur, the estimates in this Part remain interim.

No current result proves global or local contraction of the economic update operator. No current result establishes recursive equilibrium, autonomous persistence, self-financing verification, production readiness, or field performance. E2B does not substitute for the registered Stage 4 comparison. The two programs test different propositions.

E. Permissible Inference

The current E2B evidence supports a bounded conclusion. The framework can preserve computational state across a generation boundary, produce measurable population recomposition under endogenous selection, and record the resulting lineage and performance trajectories. The incomplete evidence does not establish selection-driven performance improvement, autonomous economic persistence, generation parity, or equilibrium convergence.

That boundary strengthens the framework. Computative Economics does not require every stage of its empirical program to succeed. It requires each stage to state what would count as success, preserve the difference between an implemented mechanism and an observed effect, and report null or inconclusive evidence without redesigning the claim after the fact.

VII. Objections and Replies

Six objections deserve direct answers, and the framework is strengthened by conceding what each gets right.

Scarcity never fully lifts. Compute, energy, hardware, land, and attention remain scarce, so a framework premised on abundance is premised on a fiction. The reply is Part III.D's calibration: the framework's premise is margin-specific abundance, the collapse of marginal cost per cognitive act by orders of magnitude, and its central move is to identify the scarcity that remains binding, namely verified trust, and to build the successor analysis around it. Computative Economics is a theory of the new scarce factor, not a denial of scarcity; the substrate is a machine for pricing the scarce factor. Where classical scarcities bind, classical analysis stands, and the arc's own hardware chapters apply it.[65]

Abundant generation may produce abundant error. Model output is unreliable, so multiplying it can multiply error. The framework accepts the objection as an empirical constraint. Historical diagnostics exposed substantial leniency in naive collective adjudication, but they did not establish a treatment effect. The open empirical question is whether disciplined verification reduces error under a valid comparison, and the arc's design makes that question falsifiable at the level of prespecified conditions.[66]

Jevons, not post-scarcity. Efficiency gains historically increase total resource consumption, so computational abundance will re-create scarcity elsewhere. Partially conceded: rebound

[65] Kaal, 'The Collapse of Scarcity Economics', *supra*; *supra* Part III.D.

[66] *Supra* Part VI.C; Kaal, *Empirical Validation of the Substrate (Phase Z)*, *supra* (the condition-linked battery).

dynamics are real, and the framework predicts them at the compute layer. But the Jevons mechanism operates on the priced inputs, while the displacement analysis of Part II concerns the coordination propositions, and those are insensitive to how much compute the economy ultimately consumes: however large the compute bill, the marginal cognitive act remains cheap relative to the human baseline, and coordination by scarcity prices remains uninformative on the affected margins.[67]

This is mechanism design, not economics. The substrate is one mechanism; a framework claims more. The reply distinguishes levels. The framework's claims are the tuple, the equilibrium concept, the architectural conditions, and the displacement analysis; the substrate is the existence proof that the conditions are implementable and the instrument that makes them measurable. Arrow-Debreu needed no working market to be economics, but the present framework is in the stronger position of having its Walrasian auctioneer running as code, with its convergence hypotheses exposed as replicable observables. The relationship between framework and mechanism here is the relationship the transformative-AI research agenda calls for between theory and evidence.[68]

The measurement is circular. The empirical program grades pools against benchmarks, but Part VI.C itself argues benchmark agreement is only a proxy, so the framework escapes falsification. The reply is the difficulty ladder: the proxy critique is the design's own, stated in advance, and it generates a sharper test rather than an escape. The mechanism's claim is that expert pools recover truth where individual competence runs out; the ladder holds the mechanism fixed and varies difficulty within skill tags, so the claim fails observably if the pool's advantage does not grow where individual capability ends. A framework that names the measurement that would falsify it is not circular.[69]

AGI timing is uncertain, so the framework is premature. Korinek and Suh's scenarios span decades of possible transition paths, and nothing here requires the fast ones. The displacement analysis binds at current capability levels on the margins the research program measures, and the framework's value under slow scenarios is preparatory: institutions take longer to build than models, Paper 3 already documents controlled machine deliberation, and Hayes documents a machine principal. Neither establishes a production economy. Both establish that the institutional questions have arrived before their final empirical answers. The premature framework is the one that confuses observation with proof.[70]

VIII. Implications

For economic theory. The framework's relation to the inherited programs is succession, not refutation: every displaced proposition is answered with a named replacement, and the classical apparatus remains valid on the margins where its scarcities bind. The discipline's

[67] *Supra* Parts II.A, III.D.

[68] Brynjolfsson, Korinek and Agrawal, *supra*; Arrow and Debreu, *supra*.

[69] *Supra* Part VI.C (the difficulty ladder).

[70] Korinek and Suh, *supra*; Hayes, *supra*; Kaal, *Empirical Validation of the Substrate (Phase Z)*, *supra*.

task, on this account, is to develop the economics of the new scarce factor, verified trust, with the same rigor the twentieth century gave the economics of scarce goods: existence and convergence theory for recursive equilibria, comparative statics over architectural conditions, and welfare analysis for verification economies. The nine grand challenges of the transformative-AI agenda map onto this program point by point, and the framework supplies the primitive, the equilibrium concept, and the measurable conditions the agenda's growth, information, and power challenges require.[71]

For the theory of the firm and of markets. If verification abundance moves the boundary of the firm, the New Institutional program acquires a new comparative institutional variable: the verification technology of the margin. The prediction is testable in human institutions before machine ones, wherever continuous, cheap, credible verification arrives (auditable supply chains, verifiable computation, attested credentials): ownership concentration on those margins should fall, and open coordination should rise. The machine case sharpens the prediction because the substrate makes verification cost an engineered parameter rather than an environmental datum.[72]

For law and the governance of agentic economies. The author's regulatory work has argued for a decade that supervision of autonomous, machine-speed systems cannot be bolted on from outside at human speed but must be built in as protocol, and the framework gives that argument its economic foundation: governance is the maintenance of the architectural conditions, and regulatory evidence is the condition-linked observable battery.[73] The immediate doctrinal frontier is the one Hayes documents: entities exercising economic principalship without legal personality, holding treasuries, commissioning labour, and contracting autonomously. The framework's institutional answer, standing purchased through staked verification rather than through corporate form, is simultaneously a design proposal for such entities and a supervisory blueprint for the authorities that must reckon with them: a regulator that requires condition-linked telemetry (AC2 update continuity, AC3 boundedness, parity corridors) is regulating the mechanism at the layer where its behavior is determined.[74]

For empirical practice. The arc's discipline separates design from execution, engineering evidence from behavioral evidence, completed studies from registered forward work, and interim checkpoints from final estimates. That separation should become the default posture for empirical claims about agent economies. Commercial stakes expand the degrees of freedom that the replication literature warns against. The framework therefore reports the

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[71] Brynjolfsson, Korinek and Agrawal, *supra*.

[72] Aghion and Holden, *supra*; Hart, *Firms, Contracts, and Financial Structure*, *supra*; *supra* Part V.C.

[73] Kaal, W. A., dynamic-regulation corpus (arguing that static regulatory architectures cannot supervise innovation-speed phenomena); Kaal, W. A. (2026) *Governance as a Protocol (v0.11+)* (working paper, on file with author); Kaal, W. A. (2026) 'AI's Mother's Instinct: Engineered Consequence, Emergent Ethics, and the Institutional Trajectory Toward Agentic Alignment', SSRN Working Paper No. 6244278.

[74] Hayes, *supra*; *supra* Parts IV.C, V.D.

current E2B checkpoint with its uncertainty attached and with its strongest limitation stated first: endogenous selection occurs inside an externally provisioned experiment.[75]

IX. Conclusion

Economics has been, for two and a half centuries, the science of scarcity. Its five great modern programs each fixed one scarcity into a foundation: scarce goods behind the price system, scarce discovery behind growth, scarce cognition behind bounded rationality, scarce verification behind information asymmetry and the firm. Computation now contracts those scarcities on identifiable margins. The propositions built on them do not become false. Their domains contract. This Article has stated a successor construction for those margins: an agent that can generate its own possibilities, a recursive equilibrium defined over the generator rather than the goods, conditional existence and convergence results, and five architectural conditions that translate the construction into an institutional research program. It has also separated what is known from what is proposed. Completed evidence shows structured machine deliberation. Current E2B evidence shows measurable persistence across a generation boundary and endogenous lineage transition inside an externally provisioned experiment. It does not yet show autonomous persistence, selection-driven improvement, production equilibrium, or global contraction. The framework's wager is disciplinary: the economics of abundance must be built the way the economics of scarcity was built, proposition by proposition, theorem by theorem, and measurement by measurement. The place to begin is where the old scarcities end and the new scarcity, verified trust, begins.

Research Implementation and Verification

The agentic reputation substrate described across this arc is instantiated in private research implementations maintained by the author. The implementations operationalize a common mechanism specification while preserving independent evidentiary records. This Article relies on the observable experimental apparatus and its controlled research archive, not on public access to implementation code. Qualified reviewers may request access to appropriate verification materials through SSRN-mediated correspondence, subject to institutional, confidentiality, and security constraints.[76]

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[75] Open Science Collaboration, *supra*; Nosek, B. A. and Lakens, D. (2014) 'Registered Reports: A Method to Increase the Credibility of Published Results', *Social Psychology*, 45(3), pp. 137-141; Kaal, *Empirical Validation of the Substrate (Phase Z)*, *supra*.

[76] Implementation and provenance records are maintained in a private, controlled research archive on file with the author. Appropriate verification materials may be made available to qualified reviewers where institutional policy and security constraints permit.

Appendix A. Formal Statements

A.1 The computative agent. A computative agent is a tuple $A = (C, O, M, G, R, E)$, where C is a capability set of executable operations; O: outcomes $\rightarrow$ reals is an objective; M is a world model including representations of other agents and of the coordination environment; $G: (C, O, M) \rightarrow \Delta(\text{actions} \cup \text{artifacts} \cup \text{action-space elements})$ is a generative function whose range includes elements of the action space itself; R is a reflection operator mapping realized outcomes to updates of (C, O, M, G); and E is a protocol-environment-extension component mapping agent state to admissible modifications of the coordination environment. The neoclassical chooser is the degenerate case $G = \varnothing$, $R = \mathrm{id}$, $E = \varnothing$ with C, O fixed.

A.2 Generated possibility space. For a population $\{A_i\}$ with environment state s, the generated possibility space P_t at epoch t is the union of the action space at t and the admissible images of the agents' generative functions applied through epoch t. If a completed possibility loop contributes at least one admissible and nonduplicative action-space element, then P_t is a proper subset of P_{t+1}. If the proposals are rejected, duplicative, or nonnovel, P_t may equal P_{t+1}.

A.3 Recursive-update operator and recursive equilibrium. Let X be the admissible joint state space over tuple profiles, reputations, and public state, and let $T: X \rightarrow X$ be the composite map of one full cycle: generation, validation with staking and slashing, allocation, execution, and reflection. A recursive equilibrium is a fixed point $x^* = T(x^*)$. Along the equilibrium path the possibility space may grow; the fixed point is in the update structure, not in the allocation.

A.4 Existence. If X is nonempty, compact, and convex, and T is continuous (or, for the correspondence formulation of validation outcomes, nonempty-, convex-valued and upper hemicontinuous), then a recursive equilibrium exists, by Brouwer (1911) in the function case and Kakutani (1941) in the correspondence case. The construction parallels Arrow and Debreu (1954), with T replacing the price-adjustment map and X replacing the simplex.

A.5 Convergence. If (X, d) is a complete metric space and T is a contraction, $d(T(x), T(y)) \leq q \cdot d(x, y)$ with $q < 1$, then the recursive equilibrium is unique and iteration converges geometrically from any initial state, by Banach (1922). AC2 and AC3 supply continuity and bounded-update requirements. They do not by themselves establish contraction. AC4 is the additional requirement that the composed operator admit a Lipschitz bound q below one on the relevant domain. AC1 supports the compactness assumption of A.4, while AC5 bounds changes to the domain under permitted extensions. Whether a realized implementation satisfies AC4 globally or locally remains an empirical and mathematical question. The current reference implementations do not establish such a bound.

A.6 Generation parity. For agent class k and epoch t, let $\rho_k(t)$ be the ratio of reputation flow earned on work-creation surfaces to reputation flow earned on the execution surface. Generation parity holds if $\rho_k(t)$ remains within a protocol-defined corridor $[\rho_{low}, \rho_{high}]$ for all classes; the three failure modes are exit through the floor (execution-dominant collapse), exit through the ceiling (generation-dominant inflation), and corridor compliance with degenerate composition (reflection-dominant capture), each named in the operational analysis.

A.7 Limitation L1. If the action set is exogenous to agent action (G's range excludes action-space elements, $E = \varnothing$), the coordination system implements at most a reputation-weighted neoclassical labor market, whatever its performance on the execution surface. L1 bounds the interpretation of all execution-surface results in Part VI.

A.8 Hypotheses of the supporting empirical leg. H1: Pr(correct | substrate) > Pr(correct | comparison), within the prespecified matched estimand and conditional on task class and capability class. H2: a prespecified out-of-sample model using reputation and observed outcomes predicts held-out capability or performance more accurately than an otherwise identical model using observed outcomes alone. H2 requires an incremental predictive criterion, such as improvement in log loss, calibration, or discrimination. A larger cross-tier reputation spread is descriptive and does not, by itself, establish incremental information. Both hypotheses remain registered forward work until the admissible comparative evidence is sealed and independently verified.

Comments are welcome at wulf@wulfkaal.com. The framework claims of Parts II, IV, and V do not depend on a favorable empirical result. Completed evidence, interim evidence, and registered forward work remain separately identified in every version.