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BEYOND EQUILIBRIUM: THE FUTURE OF ECONOMIC THEORY IN THE NEXT 100 YEARS

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Abstract: *The dominant paradigm of 20th-century economics—rooted in neoclassical equilibrium, rational agents, and closed-system modeling—faces compounding empirical and theoretical challenges that will reshape the discipline over the coming century. Drawing on current trajectories in complexity economics, information theory, ecological economics, behavioral science, and artificial intelligence, this article argues that economic theory will undergo at least four fundamental transformations by 2125: the dissolution of the rational-agent axiom in favor of adaptive, heterogeneous agents; the reframing of economies as open thermodynamic systems governed by entropy and irreversibility; the integration of computational intelligence as both an analytical tool and an economic actor; and the convergence of ecological carrying capacity as an inescapable boundary condition of all economic theorizing. The article surveys existing work in each domain and projects forward, identifying the theoretical architectures most likely to define the economic science of the future.*

Keywords: *complexity economics, thermodynamic economics, artificial intelligence, behavioral economics, ecological economics, post-neoclassical theory*

INTRODUCTION

Every century tends to be defined by a foundational rupture in economic thought. The 19th century gave birth to marginalism and the mathematical formalization of value theory [21, p. 1]. The 20th century saw Keynesian macroeconomics rise and partially recede, followed by the consolidation of the neoclassical synthesis, game theory, and behavioral economics.

As we enter the 21st century, the pressures mounting against the discipline's canonical frameworks are not merely empirical anomalies to be corrected at the margins—they constitute structural inadequacies.

Three crises converge simultaneously. First, the 2008 global financial collapse exposed the explanatory bankruptcy of dynamic stochastic general equilibrium (DSGE) models, which not only failed to predict the crisis but provided no tractable theory of systemic instability [30, p. 591]. Second, accelerating ecological disruption—most acutely anthropogenic climate change—has revealed the limits of treating the natural world as an externality rather than a boundary condition [15, p. 1]. Third, the proliferation of artificial intelligence and algorithmic decision-making has introduced nonhuman agents into markets at scales and speeds that existing microeconomic frameworks were not designed to accommodate [34, p. 27].

This article does not predict the future with certainty; such a claim would be epistemically dishonest. Instead, it identifies the fault lines where theoretical pressure is greatest, surveys the embryonic frameworks already developing along those lines, and projects the directions most likely to dominate economic thought over the next hundred years.

2. THE DISSOLUTION OF HOMO ECONOMICUS

The Behavioral Revolution and Its Incomplete Resolution

The behavioral economics revolution, inaugurated by Kahneman and Tversky's prospect theory [22, p. 263] and institutionalized through Thaler's nudge framework [33, p. 6], has established beyond reasonable dispute that human decision-making systematically deviates from the predictions of expected utility maximization. Loss aversion, hyperbolic discounting, status quo bias, and social preferences are not noise—they are features of human cognition with deep evolutionary origins [12, p. 3].

Yet behavioral economics, as currently constituted, remains a set of modifications grafted onto a neoclassical trunk. The rational agent is not replaced; it is corrected. This grafting strategy is intellectually awkward and theoretically limiting. The future of economic theory will likely involve a more radical step: the complete abandonment of the representative agent as an analytical device.

Agent-Based Modeling and Heterogeneous Populations

The alternative already exists in embryonic form. Agent-based computational economics (ACE), developed systematically by Tesfatsion and Epstein, treats economies as emergent phenomena arising from the interactions of heterogeneous agents governed by adaptive rules rather than optimization [17, p. 1; 32, p. 831]. These models can generate realistic distributions of wealth, realistic financial crises, and realistic macroeconomic dynamics without presupposing that any single agent solves an intertemporal optimization problem.

Over the coming century, improvements in computational power and the availability of granular behavioral data—from transaction records, social networks, and digital platforms—will make ACE models increasingly tractable and empirically disciplined. The theoretical future likely belongs not to the representative rational agent but to populations of interacting, learning, and socially embedded decision-makers whose aggregate behavior is irreducible to individual optimization [5, p. 107; 18, p. 685].

This shift carries profound normative implications. Welfare analysis—the core of policy economics—becomes dramatically more complex when preference heterogeneity is taken seriously and when preferences themselves are endogenous, shaped by social interaction and institutional context [29, p. 74].

ECONOMIES AS OPEN THERMODYNAMIC SYSTEMS

Georgescu-Roegen and the Entropy Law

The deepest structural critique of mainstream economic theory is one that has been present since the 1970s but remains largely outside the discipline's mainstream: the argument that economic processes are irreversible thermodynamic transformations, not circular flows of value. Nicholas Georgescu-Roegen's magisterial work, *The Entropy Law and the Economic Process*, argued that economic production is, at its physical core, the conversion of low-entropy matter and energy (raw materials, fossil fuels) into high-entropy waste. This process is irreversible—it cannot be undone by any price signal or market mechanism [19, p. 2].

Mainstream economics has largely ignored this insight, or subordinated it to the logic of substitution: if one resource runs out, another will take its place, provided prices function correctly. This substitutability assumption is the theoretical foundation of weak sustainability. Georgescu-Roegen regarded it as physically incoherent [19, p. 281].

The Biophysical Economics of the 22nd Century

The ecological crises accumulating in the 21st century will force a confrontation with thermodynamic limits that substitutability logic cannot indefinitely defer. Energy economics will move from the periphery to the center of the discipline. The work of Ayres and Warr, demonstrating that the productive capacity of advanced economies is explained far better by useful energy (exergy)

than by conventional factor inputs, points toward a biophysical economics that measures economic activity in energy and material terms alongside—or instead of—monetary ones [8, p. 1].

Future economic theory will likely develop rigorous accounts of the energy return on investment (EROI) of different productive activities, the thermodynamic efficiency of economic institutions, and the hard boundaries imposed by planetary carrying capacity [20, p. 1]. The transition from fossil fuels to renewable energy systems—which is itself a thermodynamic transformation of enormous complexity—will necessitate theoretical tools that current economics does not possess.

It is plausible that by 2125, economic theory will routinely integrate material flow analysis, life-cycle assessment, and second-law thermodynamics into its core analytical apparatus, treating GDP not as a measure of welfare but as a proxy for entropy production that must be evaluated against its biophysical costs [16, p. 15].

ARTIFICIAL INTELLIGENCE AS ECONOMIC ACTOR AND THEORIST

The Transformation of Markets by Algorithmic Agents

The integration of artificial intelligence into economic life is not a future event—it is an ongoing transformation whose implications are not yet theoretically absorbed. High-frequency trading algorithms already execute the majority of equity market transactions in major financial centers; pricing algorithms coordinate prices across digital platforms at speeds and scales impossible for human actors; recommendation systems shape consumption patterns for billions of people [7, p. 3; 10, p. 7].

These algorithmic agents raise questions that existing economic theory is ill-equipped to answer. Do they maximize utility? They optimize objective functions, which is related but not identical. Do they have preferences? In a formal sense, yes—but those preferences are engineered by their designers, not formed through experience or social interaction. Do they engage in strategic behavior? Unambiguously yes, and in ways that can produce emergent equilibria—including undesirable ones such as algorithmic collusion—that no human regulator designed or anticipated [11, p. 3267].

AI as Economic Theorist

More speculatively but not implausibly, artificial intelligence may become not merely an object of economic analysis but a producer of economic theory. Large language models already synthesize economic literature with considerable sophistication; future systems may be capable of generating novel theoretical frameworks, identifying empirical regularities in large economic datasets, and producing policy recommendations that outperform those of human economists in narrow domains [3, p. 1].

This raises philosophical questions that lie at the boundary of economics and epistemology: What is the status of a theory produced by a system that does not have interests, cannot be held accountable, and cannot explain its reasoning in terms intelligible to human practitioners? The sociology and philosophy of economic knowledge will be transformed alongside the knowledge itself.

The most likely outcome over the coming century is a division of theoretical labor: AI systems will handle the empirical and computational tasks of economic analysis—simulation, pattern recognition, prediction—while human economists will focus on the normative, interpretive, and institutional dimensions that require judgment, ethical reflection, and political accountability [13, p. 1].

PLANETARY BOUNDARIES AS CONSTITUTIVE ECONOMIC CONSTRAINTS

The End of Externalities as a Theoretical Category

The concept of the externality—a cost or benefit not captured in market prices—has been the standard tool for incorporating environmental considerations into economic analysis since Pigou [26, p. 183]. Externalities are, in principle, correctable by appropriate taxes or regulations that internalize

the social cost. This framing treats the environment as an input to the economic system that can be priced and thereby managed.

As Rockström et al. demonstrated, however, certain ecological boundaries—atmospheric CO₂ concentration, biodiversity loss, nitrogen cycling—are not merely large externalities. [28, p. 472]. They are thresholds beyond which the Earth system undergoes qualitative regime shifts that cannot be undone within any economically relevant time horizon. Crossing these boundaries does not produce a correctable cost; it changes the operating conditions for all economic activity indefinitely.

Future economic theory will have to reconceptualize the relationship between the economy and the biosphere. Rather than treating nature as an external input to be priced, it will treat the economy as a subsystem of the biosphere, bounded by physical and biological limits that are non-negotiable [15, p. 49]. This is not a minor modification of existing theory—it is a Copernican inversion of the standard framing.

Degrowth, Post-Growth, and Steady-State Frameworks

Economic growth—measured as increasing GDP—has been the central objective of macroeconomic policy for the entirety of the discipline's modern history. The compatibility of perpetual growth with ecological sustainability is, however, increasingly contested. The degrowth movement and the steady-state economics tradition argue that a transition to an economy that operates within ecological limits will require not just greening of growth but a fundamental rethinking of what the economy is for [14, p. 1; 18, p. 685; 20, p. 1; 23, p. 1].

Over the next century, as climate impacts intensify and resource constraints tighten, economic theory will be forced to develop rigorous frameworks for economies that prioritize human flourishing within ecological limits rather than aggregate output expansion. Wellbeing economics, capabilities approaches, and doughnut economics represent early explorations of this theoretical space [25, p. 20; 27, p. 1; 29, p. 18; 31, p. 1].

THE RETURN OF INSTITUTIONS AND POLITICAL ECONOMY

Economics in the 20th century increasingly aspired to be a value-free positive science, separating descriptive analysis from normative prescription. The political economy tradition—which treated markets as embedded in social relations, power structures, and institutional arrangements—was subordinated to the mathematical optimization tradition. This separation was always somewhat artificial, and future economic theory will likely erode it further.

Over the coming century, the intersection of artificial intelligence, ecological constraint, and rising inequality will make the political economy of economic institutions—who controls the rules, who benefits from them, and how they can be changed—increasingly central to the discipline. Economic theory will become more, not less, political in the sense of engaging explicitly with questions of power, justice, and collective choice [9, p. 1].

TOWARD A UNIFIED FRAMEWORK: COMPLEXITY, ENERGY, AND INSTITUTIONS

The four transformations described above—from rational agents to adaptive heterogeneous agents, from closed systems to open thermodynamic systems, from human to hybrid human-AI economies, and from externalities to constitutive ecological constraints—are not independent. They converge on a common theoretical vision: economies are complex adaptive systems, nested within ecological systems, governed by institutions that encode power relations, and increasingly mediated by artificial intelligence.

The science of complexity—developed by the Santa Fe Institute research program since the 1980s (Anderson, Arrow, Pines, Arthur) provides the most developed framework for integrating these elements. Complex systems exhibit emergence, path dependence, sensitivity to initial conditions, and self-organization: all properties that characterize real economies but are absent from

equilibrium models [4, p. v; 6, p. 1]. The complexity economics of Doyne Farmer, Brian Arthur, and Eric Beinhocker represents the most promising existing trajectory for the unified theory of the future.

What remains underdeveloped in complexity economics is its normative dimension. A positive science of complex economic systems is insufficient; economic theory must also provide guidance for collective action under conditions of deep uncertainty, irreversibility, and power asymmetry. The integration of complexity with political economy and ethics will be the central theoretical challenge of economic science in the century to come.

CONCLUSION

The future of economic theory is not a linear extrapolation from the present. It is a series of paradigm shifts, some already underway, that will transform the discipline's ontology (what economies are), epistemology (how we know about them), and normative commitments (what they are for). The rational agent, the closed market system, and the externality-correctable environment will give way to adaptive agents, open thermodynamic systems, and constitutive ecological limits. Artificial intelligence will reshape both the object of economic analysis and the methods of conducting it.

These transformations will not occur smoothly or uniformly. Institutional inertia within the discipline, the vested interests of those whose careers are invested in existing frameworks, and the genuine difficulty of the theoretical problems involved will ensure that the transition is contested and prolonged. But the convergence of ecological crisis, technological disruption, and the accumulating empirical failures of existing theory makes fundamental transformation inevitable.

The economists of 2125 will look back at the neoclassical synthesis much as contemporary physicists look back at Newtonian mechanics: as a powerful and productive framework within its domain of validity, but one whose limits, once exceeded, demanded something genuinely new. The work of building that something new has already begun.

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**TARAZLIQDAN KƏNAR: NÖVBƏTİ 100 İLDƏ İQTISADI NƏZƏRİYYƏNİN
GƏLƏCƏYİ**

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Xülasə: XX əsr iqtisadiyyatının hakim paradigması – neoklassik tarazlıq yanaşması, rəşional agent fərziyyəsi və qapalı sistem modelləşdirməsinə əsaslanan nəzəri çərçivə qarşıdakı yüzillikdə bu elm sahəsinə yenidən formalaşdıracaq olan və getdikcə artan empirik və nəzəri çağırışlarla üz-üzədir. Mürəkkəblik iqtisadiyyatı, informasiya nəzəriyyəsi, ekoloji iqtisadiyyat, davranış elmləri və süni intellekt sahələrində müşahidə olunan müasir elmi istiqamətlərə əsaslanaraq, bu məqalədə iddia olunur ki, 2125-ci ilə qədər iqtisadi nəzəriyyə ən azı dörd fundamental transformasiyaya məruz qalacaqdır: rəşional agent aksiomunun adaptiv və heterogen agentlər konsepsiyası ilə əvəzlənməsi; iqtisadi sistemlərin entropiya və geri dönməzlik prinsipləri ilə idarə olunan açıq termodinamik sistemlər kimi yenidən konseptuallaşdırılması; hesablamə intellektinin həm analitik alət, həm də iqtisadi subyekt kimi iqtisadi modellərə integrasiyası; ekoloji daşıma qabiliyyətinin bütün iqtisadi nəzəriyyələ üçün qaçılmaz sərhəd şərti kimi qəbul edilməsi. Məqalədə hər bir istiqamət üzrə mövcud elmi ədəbiyyat sistemli şəkildə təhlil edilir və gələcəyə yönəlik proqnozlar irəli sürülərək, gələcəyin iqtisadi elmini müəyyən edəcək nəzəri arxitekturalar müəyyənləşdirilir.

Açar sözlər: mürəkkəblik iqtisadiyyatı, termodinamik iqtisadiyyat, süni intellekt, davranış iqtisadiyyatı, ekoloji iqtisadiyyat, post-neoklassik nəzəriyyə

**ЗА ПРЕДЕЛАМИ РАВНОВЕСИЯ: БУДУЩЕЕ ЭКОНОМИЧЕСКОЙ ТЕОРИИ В
БЛИЖАЙШИЕ 100 ЛЕТ**

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Аннотация: Доминирующая парадигма экономической науки XX века основанная на неоклассическом равновесии, предпосылке рационального агента и моделировании замкнутых систем сталкивается с нарастающими эмпирическими и теоретическими вызовами, которые в течение следующего столетия приведут к существенной трансформации данной дисциплины. Опираясь на современные направления развития экономики сложности, теории информации, экологической экономики, поведенческих наук и искусственного интеллекта, в настоящей статье обосновывается тезис о том, что к 2125 году экономическая теория претерпит по меньшей мере четыре фундаментальные трансформации: отказ от аксиомы рационального агента в пользу адаптивных и гетерогенных агентов; переосмысление экономики как открытой термодинамической системы, подчиняющейся законам энтропии и необратимости; интеграция вычислительного интеллекта как аналитического инструмента и одновременно как экономического актора; признание экологической ёмкости (предельной несущей способности) в качестве неотъемлемого граничного условия всякого экономического теоретизирования. В статье проводится обзор существующих исследований по каждому из указанных направлений и формулируются перспективные прогнозы, позволяющие выявить теоретические архитектуры, способные определить облик экономической науки будущего.

Ключевые слова: экономика сложности, термодинамическая экономика, искусственный интеллект, поведенческая экономика, экологическая экономика, постнеоклассическая теория