Journal of Economic Behavior and Organization 235 (2025) 107049

Contents lists available at ScienceDirect

Journal of Economic Behavior and Organization

journal homepage: www.elsevier.com/locate/jebo

Editorial

Complex systems approaches to 21st century challenges: Introduction to the Special Issue[☆]

Over the past decades, the global economy has experienced profound transformations, propelled by rapid technological change, a changing geopolitical landscape, and the urgent need for a net-zero carbon transition. These shifts pose difficult analytical challenges, requiring approaches that capture real-world agent heterogeneity, detailed institutional structures, out-of-equilibrium dynamics, and uncertainty.

Complexity economics provides a powerful framework for meeting these challenges. Complexity economics models the economy from the bottom up, attempting to capture agents' behavior and institutional patterns realistically. This approach integrates interactions of agents and institutions by drawing on decades of research on complex systems and networks, and aims to explicitly incorporate feedback loops that can drive a system away from equilibrium and generate nonlinear dynamics.

This Special Issue of the *Journal of Economic Behavior & Organization* highlights some of the latest advances in complexity economics. This initiative stems from the conference "Complex Systems Approaches to 21st Century Challenges: Inequality, Climate Change, and New Technologies", held at the Santa Fe Institute on July 31st–August 2nd, 2023.[1] The conference welcomed around 40 participants, with sessions on the green transition, risk and resilience, inequality, technology, political fragmentation, ABM methods, and the application of complexity economics methods in industry and policy making. The conference triggered two edited volumes: A book edited by Santa Fe Institute Press, which gathers perspectives and reviews, which we will often highlight in this introduction; and this Special Issue, gathering research articles.[2]

The articles in this special issue contribute to six broad research themes: climate economics, inequality and institutions, technological change, production networks, macroeconomics, and agent-based modeling methods. The contributions reflect the growing methodological maturity and policy relevance of complexity economics. Most are empirically grounded in data, calibrated to real-world settings, or focused on pressing policy issues, including climate resilience, housing markets, inequality and technological disruption. Together, these papers make a compelling case for complexity-informed approaches to advance the theory and practice of economic behavior and organization.

1. Climate economics

Understanding and managing the economic dimensions of climate change is among the most pressing challenges of our time. The complexity of this task stems not only from the physical dynamics of the Earth system but also from the interplay of social, technological, and economic forces that drive emissions and shape vulnerability to climate shocks. This means that we have to deal with (i) physical risk – direct and cascading losses from hazards – where complexity economic tools can trace the impacts from neighborhood level damage to macroscale disruption (Filatova and Akkerman, 2025), and (ii) transition risk — the economic, financial and political instabilities that emerge endogenously during rapid decarbonization, a process that also demands a bottom-up lens of adaptive systems (Lamperti et al., 2025; Battiston and Monasterolo, 2025). Two papers in this Special Issue exemplify how complexity-based approaches can model both sides of the climate-risk coin: an opinion-dynamics ABM investigates transition risk by

☆ We would like to thank the Santa Fe Institute for hosting the conference that stimulated this Special Issue, and Daniela Puzzello for her guidance in editing it. The work in this special issues was supported in part by a Santa Fe Institute, United States grant from the Omidyar Network, by Baillie Gifford and by the UKRI through ESRC grant PRINZ (ES/W010356/1).

[1] https://www.santafe.edu/info/complex-system-approaches-21st-century-challenges-inequality-climate-change-and-new-technologies/home

[2] Submission to the Special Issue was open to all (the majority of authors in this issue did not attend the conference), and articles have been peer-reviewed.

https://doi.org/10.1016/j.jebo.2025.107049

Available online 19 May 2025

modeling the social and political support for carbon taxation, while a high-resolution, network-based input–output model quantifies the economic consequences of a major flood, showcasing complexity economics in the realm of physical risk.

Lackner et al. (2025) introduce opinion dynamics in an ABM to study effective carbon taxation. Effective climate policy is essential for achieving net-zero emissions, yet ambitious measures such as carbon taxes often face public resistance, limiting their political feasibility. This paper examines which pathways to net-zero can sustain public support by analyzing how opinion on climate policy evolves alongside carbon taxation. Using an opinion dynamics model integrated with a macroeconomic agent-based climate model, the authors analyze 133 policy scenarios to assess how different tax and revenue recycling strategies shape public attitudes. Their findings show that while high carbon taxes initially reduce support due to economic adjustment costs, they can eventually trigger a positive tipping point as the fossil fuel industry's influence declines. Policies that combine carbon taxes with green subsidies and direct climate dividends are most effective in maintaining long-term public backing while accelerating the transition.

Building on dynamic shock propagation models developed during the Covid-19 pandemic (Reissl et al., 2022, 2024; Pichler et al., 2022), Di Noia et al. (2025) introduce IRIO-Flood, a computational input–output model that assesses flood-induced economic losses in Italy with high geographical and sectoral resolution. The model integrates geo-referenced plant data with flood maps to quantify sectoral shocks and employs non-linear shock propagation to improve accuracy. The model, calibrated to Covid-19 lockdown data, captures direct and indirect losses from the 2023 Emilia-Romagna flood, revealing initial supply shocks, delayed demand effects, and regional spillovers. Results show that short-term GDP losses are significant but followed by a partial rebound as sectors restock inventories. The framework, based on public data, offers a scalable tool for disaster impact assessment.

2. Inequality and institutions

Inequality is not only a distributional outcome or a static snapshot of who has what. Inequality is a dynamic and deeply embedded characteristic of economic and social systems. It emerges from the complex interplay of individual life events, institutional contexts, and the social networks that shape how people perceive their relative standing. Understanding how inequality is created, experienced, transmitted, and potentially mitigated requires analytical approaches that move beyond static indicators and instead reflect agent heterogeneity, the interdependence of life domains and the localized nature of social comparison — features best understood through a complex systems lens that distinguishes between bottom-up dynamics and top-down structural constraints (Durlauf et al., 2025).

Three papers in this Special Issue address these challenges from different lenses: The first uses a microsimulation model to study the longer-term evolution of inequality and recovery from key shocks. The second develops a novel measure of experienced inequality based on local social ties. The third contributes a theoretical model of the coevolution between cultural capacity and institutional performance, showing how institutions and norms mutually can shape, and sometimes even undermine, each other. Together, these contributions demonstrate how complexity-informed approaches can uncover the micro-to-macro mechanisms that sustain inequality and offer new tools for designing institutions and policies that are more responsive to real-world dynamics.

Richiardi et al. (2025a) use a microsimulation model[3] to examine how life shocks, such as partnership dissolution and sudden health deterioration, contribute to long-term inequality in health and economic outcomes. Measuring these effects is difficult because jobs, health, and family life interact, making it hard to isolate cause and effect from real-world data. The authors separate the direct impact of these shocks from the ripple effects they trigger. The results show that after a breakup, many people recover over time – re-partnering and returning to work – demonstrating attenuation mechanisms that help absorb the shock. In contrast, a sudden health decline has fewer pathways to recovery, reinforcing disadvantage through long-term unemployment and financial strain. This method helps policymakers identify who is most at risk and design interventions to prevent setbacks from deepening inequality.

Mamunuru et al. (2025) show that people experience inequality "locally", through their close network connections. Standard inequality measures, such as the Gini coefficient, assume that people compare themselves to everyone in society, but in reality, individuals experience inequality through local social networks. This paper develops a measure of experienced inequality, which accounts for how social connections shape perceptions of inequality, and applies it to 75 villages in Karnataka, India. The findings show that the Gini coefficient overestimates experienced inequality in 25 villages and underestimates it in 50 villages, depending on the network structures. Specifically, when people mainly interact with others of similar wealth (wealth homophily), experienced inequality is lower, while caste-based homophily reduces experienced inequality only when wealth differences within castes are smaller than overall village inequality. These results suggest that social networks play a crucial role in shaping perceptions of inequality and may influence attitudes toward redistribution and social mobility.

Bednar and Page (2025) develop a theoretical model of the coevolution of institutional performance and cultural capacity, where the latter is defined as the beliefs, behaviors, norms, and networks that enable institutions to function. They show that institutional outcomes depend not only on design features but also on whether individuals possess the cultural traits needed for success, and vice versa. The key result is that equilibria where institutions and culture are mutually reinforcing are generally inefficient, due to a disconnect between producing and leveraging cultural capacity. Paradoxically, institutions that generate broadly beneficial cultural capacities may undermine their own persistence, as they make competing institutions relatively more effective. The paper also highlights how dominant institutions, like markets, can inadvertently erode others, like democracies, by cultivating cultural traits incompatible with their operation.

[3] Microsimulation models simulate individual-level trajectories using empirically grounded transition rules. While traditionally less focused on interactions, they share with agent-based models (ABMs) focus on the evolution of a system through maps rather than solving for equilibrium (Richiardi et al., 2025b).

3. Technological change

Technological change is a fundamental driver of economic transformation, often unfolding in disruptive and non-linear ways. Its study has long been central to evolutionary, Schumpeterian and complexity economics traditions. And with technologies such as artificial intelligence becoming more widely and rapidly deployed, the policy imperative for better understanding its socio-economic consequences has never been greater. While technological progress can to some extent be predicted (Lafond, 2025), when breakthroughs reshuffle skill demand at machine speed, bounded-rational firms and workers often struggle to adjust, making labor-market resilience a policy priority (del Rio-Chanona et al., 2025). This Special Issue includes two contributions that pick up on these themes: one documenting how generative AI rapidly reshapes labor demand, and another showing how predictive tools can anticipate shifts in technological complexity in cities.

The first paper (Teutloff et al., 2025) provides a state-of-the-art investigation on the theme of technology and labor markets. Generative AI is transforming labor markets, but its effects vary across different types of jobs. This paper examines how the introduction of ChatGPT has shifted demand for freelancers in skills that can be substituted or complemented by large language models (LLMs). Using LLM embedding spaces, the authors identify 116 fine-grained skill clusters and classify them as substitutable, complementary, or unaffected. A difference-in-differences analysis shows that demand for substitutable skills, such as writing and translation, declined by 20%–50%, while demand for complementary skills was more nuanced — tripling for AI-powered chatbot development but declining for novice workers overall. This study documents how GenAI is reshaping labor demand and suggests that non-equilibrium models could help explore how workers reallocate in response to shifting demand. Policy-wise, it highlights that the benefits for complementary tasks are unevenly distributed.

The second paper falls in the domain of "economic complexity" – a method to extract latent variables from data to reveal both the intrinsic capabilities of actors and predict their evolution (Neffke et al., 2025). Nutarelli et al. (2025) set out to analyze and predict the technological complexity of global cities. They develop a dataset that links patents to the cities of their inventors, allowing them to compute the technological comparative advantage of cities. To predict the evolution of this system, they proceed in two steps. First they use a community detection algorithm to cluster similar cities, thus creating homogeneous training sets that improves the predictive power, interpretability, and computational efficiency of the subsequent supervised learning task. Next, they compare the use of different supervised machine learning methods to predict the future revealed technological advantage of cities, five years ahead. They find that random forests perform best, achieving an F1-score of 80%. The policy implications of such predictions include identifying emerging technologies to guide investment, attracting and retaining talent by leveraging sector-specific strengths, and improving urban planning. The analysis can also inform strategic city-to-city collaborations, and support targeted migration to high-potential areas.

4. Production networks

Local disruptions can cascade through production networks, resulting in amplified and more widespread economic impacts than the initial shocks would suggest. Consequently, the integration of production network data is key for many economic models, for instance, disaster models (Filatova and Akkerman, 2025).

An example is Di Noia et al. (2025), already introduced above, who initialize their computational model for studying the impacts of floods with regional industry-level input–output data. Another contribution in this special issue building on input–output networks for modeling disaster impact is Pichler et al. (2024) who analyze the resilience to energy shocks. In 2022, the threat of a sudden halt in Russian gas exports posed a major risk to European economies, with Austria being particularly vulnerable due to its extremely high dependency on Russian gas. This paper analyzes the economic impact of such a shock using a techno-economic approach, assessing supply and demand countermeasures, sectoral output losses, and broader economic effects through a dynamic input–output model. Key short-term policy measures – securing alternative imports, managing storage, and promoting fuel switching – play a crucial role in reducing disruptions. The study quantifies the effectiveness of these measures in mitigating gas shortages and economic consequences. Results show that economic impacts vary from mild to severe, depending on the success of mitigation measures, which in turn is highly dependent on the level of supranational coordination during the crisis.

A firm's position within the complex network of supplier-buyer linkages influences its potential role in the transmission of economic shocks. To assess the relative position of individual nodes in the "chain" of production, metrics like upstreamness (the distance between the firm's output and final consumers) and downstreamness (the distance between the firm's inputs and primary factors) have been proposed. Counterintuitively, these measures are highly correlated in empirical production networks (Miller and Temurshoev, 2017). Various explanations such as the rise of service sectors or trade barriers have been offered to resolve this puzzle (Antràs and Chor, 2018). In this context, Vivo et al. (2025) provide a fundamental insight: this empirical phenomenon can be explained solely through structural properties of how the economic data is collected and organized.

The authors use null models of randomized matrices that are constrained only by basic accounting relationships, finding consistent positive correlations with a slope near +1 across different random models. These results suggest that the relationship between upstreamness and downstreamness is heavily influenced by key input–output identities resulting from the national accounts. The approach of Vivo et al. (2025) provides a simpler and more parsimonious explanation for the empirical puzzle than alternatives relying on extensive economic theory. Furthermore, these findings point at the need for caution when interpreting centrality measures such as upstreamness and downstreamness in global value chains.

5. Macroeconomics

Macroeconomics is a natural domain of application of Complexity Economics. Modeling the macroeconomy involves modeling heterogeneous agents and institutions, which agent-based models offer to do flexibly. Moreover, there is a long tradition in macroeconomics of studying aggregate fluctuations and co-movement, features that can be interpreted as signs of endogenous instability or emergent coordination (Beaudry et al., 2025). These features have long drawn the attention of complex systems scientists, and have led to the suggestion that macroeconomic systems may operate near critical points where small shocks can have out-sized effects (Bouchaud, 2025). Two papers in this SI reflect this.

Pangallo (2025) addresses a longstanding puzzle in international economics: why do models that generate business cycle comovement from exogenous shocks fall short of matching the high levels observed in empirical data? To tackle this issue, the paper draws on synchronization theory — a framework from complexity science used across disciplines to explain phenomena such as synchronized clapping in audiences or flashing in firefly swarms. The study demonstrates that when countries generate business cycles endogenously, their non-linear dynamics naturally synchronize, creating sufficient comovement to align with empirical observations. This finding suggests that business cycles are partly driven by endogenous forces, with economic booms potentially setting the stage for subsequent busts, indicating that policies designed to curb overheating could help prevent recessions.

Bardoscia et al. (2025) examine how borrower and lender-based prudential policies affect the UK housing market, credit system, and broader economy. Building on two prior ABMs (Popoyan et al., 2017; Carro, 2023), the model incorporates heterogeneous households, firms, and banks that interact via a goods, labor, financial, and housing markets, under the guidance of a Central Bank and Government. The model is calibrated to UK data and used to test three policy scenarios: increased capital requirements, a soft loan-to-income (LTI) cap, and both combined. Results show that while capital requirements reduce lending and housing transactions without easing price-to-income ratios, the LTI cap effectively lowers house prices but also increases buy-to-let activity, reshaping the rental market. Importantly, the paper finds that the impact of policies is not additive: the sum of the impact of standalone levers is considerably larger than their combined impact.

6. Agent-based modeling methods

Agent-based models (ABMs) have historically been very useful to develop and explore theories. In recent years, however, the growing availability of detailed micro-data and the development of new methods made ABMs increasingly data-driven. This is helping overcome traditional ABM limitations, making ABMs a compelling alternative to traditional models (Pangallo and del Rio-Chanona, 2025). This SI features several papers that contribute meaningful methodological advances to these efforts.

In agent-based models (ABMs), the system evolves through a complex state space, often moving away from steady states. As a result, shocks applied at different points in time can yield varying effects. Despite this, practitioners typically average impulse response functions over time, partly due to the lack of principled methods for identifying state-dependent differences. Amendola and Pereira (2025) address this gap by introducing a novel method and accompanying R library that automatically detects distinct states where impulse responses diverge. Applying their approach to a standard macroeconomic ABM, they demonstrate that the impact of monetary policy is highly state-dependent: during banking crises, interest rate hikes are especially counterproductive, whereas in normal conditions they are relatively more effective for managing inflation. Such insights, which standard methods would overlook, will help disseminate the unique analytical advantages of ABMs.

To better capture the dynamics of specific economies, researchers are moving beyond traditional parameter calibration in agent-based models (ABMs) toward estimating agent-level latent variables, aligning the system's micro-state with real-world data (Monti et al., 2023). This approach, known as data assimilation, has been widely used in the geosciences for decades but has only recently been applied to ABMs. Oswald et al. (2025) is among the first to implement this technique in economic ABMs, estimating latent agent-level wealth to ensure that key quantiles of the wealth distribution track empirical dynamics over the past 30 years, including the rising share of the top 1%. This method allows ABMs to provide real-time, more accurate estimates of wealth inequality, enabling policymakers to make better-informed decisions in rapidly evolving scenarios such as pandemic responses or natural disasters.

Hosszú et al. (2025) develops a protocol for assessing how downscaling – using a subset of agents – affects the performance of agent-based models (ABMs), a common but underexplored practice in complexity economics. The study identifies three mechanisms through which scaling influences results: idiosyncratic shocks, interaction loss, and distribution misrepresentation. Using a housing market ABM, it evaluates trade-offs between accuracy, precision, and runtime across scaling levels, showing that while moderate downscaling (25%) has little impact, extreme downscaling (0.25%) degrades model reliability. The paper also shows that upscaling small samples can mitigate data limitations. It concludes that scaling choices materially affect outcomes and that sensitivity analysis should accompany scaling decisions.

7. Conclusion

This Special Issue captures a particularly vibrant moment in the evolution of complexity economics. Over the past decade, the field has made substantial methodological strides, largely enabled by access to high-resolution microdata and the growing demand for tools that can address the interconnected and adaptive nature of economic systems. While network-based approaches and agent-based modeling were once somewhat peripheral, they are increasingly gaining traction as essential components of a broader empirical and theoretical agenda. The contributions in this volume reflect this shift, demonstrating how complexity economics is moving toward greater rigor and practical relevance.

The papers span a wide range of domains, illustrating how methodological innovations in complexity economics are being applied to diverse and incredibly important policy contexts. In climate economics, we see models that combine behavioral feedbacks and opinion dynamics with policy scenario testing, as well as network-based assessments of disaster impacts using high-resolution spatial data. In the study of inequality and institutions, new microsimulation and theoretical frameworks account for path dependence, social networks, and the co-evolution of norms and institutions. Papers on technological change apply machine learning and embedding techniques to analyze labor market disruptions and forecast city-level innovation trajectories. Macroeconomic contributions leverage tools from synchronization theory and stock-flow consistent ABMs to explore endogenous business cycles and the unintended consequences of financial regulation. Finally, methodological papers push the frontier of agent-based modeling with new techniques for state-dependent analysis, scaling protocols, and data assimilation — addressing long-standing challenges in calibration, estimation, and model interpretability.

What unites these diverse contributions is a shared commitment to modeling economies as evolving, adaptive systems composed of heterogeneous agents embedded in institutional and networked environments. Complexity economics offers formal tools for capturing interactions, feedbacks, and emergent dynamics that are difficult to represent in conventional models. The methodological advances highlighted in this issue show that complexity-informed approaches are not only conceptually rich, but increasingly operational, providing robust, scalable frameworks for simulation, inference, and policy analysis.

Looking ahead, the research frontier in complexity economics lies in continued integration of methodological innovation with empirical validation and policy relevance. Advances in computational capacity and the availability of detailed behavioral, spatial, and transaction-level data open new opportunities for estimation, validation, and counterfactual policy evaluation. As the tools of complexity economics mature, they are increasingly capable of engaging with the core questions of economic behavior and organization and linking micro-level mechanisms to macro-level outcomes across climate, inequality, finance, innovation, and institutional change. The papers in this Special Issue represent significant steps in this direction, and we hope they encourage further methodological development and applied exploration within the growing community of complexity economists.

We extend our gratitude to all authors, reviewers, and the JEBO editors who contributed to this SI. We hope that readers will find the resulting collection both thought-provoking and indicative of the rich potential that complexity economics and ABMs hold for understanding and navigating our rapidly evolving world.

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