

# ANNALES

ACTA ACADEMIAE SCIENTIARUM INSTITUTI BONONIENSIS

CLASSIS SCIENTIARUM MORALIUM



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# Workshop on “Complexity in Socio-Economic Systems: The Connectivity Approach”

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## Abstract

On June 6, 2024, the Accademia delle Scienze dell’Istituto di Bologna hosted a workshop on “Complexity in Socio-Economic Systems: the Connectivity Approach”, coordinated by Ivano Cardinale, Aura Reggiani, and Roberto Scazzieri. The workshop developed research lines addressed in a Special issue of the journal *Networks and Spatial Economics* (NETS), edited by the workshop coordinators in 2022. The workshop focused on three questions: what are the research perspectives on the architecture of complexity of socio-economic systems; what is the role of the architecture of connectivity in shaping complex subsystem-system dynamics in the socio-economic sphere; which contribution can be expected from a structural connectivity framework in shaping the design and implementation of policies. Keynote lectures by Terry Friesz, Kieran Donaghy and Ariel Wirkierman were followed by general discussion and concluding remarks by Alberto Quadrio Curzio.

## Keywords

Connectivity architectures, Network design and complexity, Circular flow economy, Network vulnerability and resilience, Structural specification and policy objectives.

On June 6, 2024, the Accademia delle Scienze dell'Istituto di Bologna hosted a workshop on “Complexity in Socio-Economic Systems: the Connectivity Approach”, coordinated by Ivano Cardinale, Aura Reggiani, and Roberto Scazzieri. The workshop aimed to develop lines of research addressed in a special issue of the journal *Networks and Spatial Economics* (NETS), edited by Cardinale, Reggiani and Scazzieri in 2022. In turn, that special issue built on themes previously explored within the interdisciplinary research program “I-CORE: Interconnectivity and Resilience” coordinated by Raffaella Campaner (Department of Philosophy, Bologna University). The I-CORE project aimed to discuss robustness, resilience, and vulnerability for different types of ruptures and discontinuities from a complex systems perspective. The NETS special issue aimed to emphasize the role of connectivity in explaining the vulnerability and resilience of complex socio-economic networks. A central feature of connectivity in a complex network is that «a given network may be host to different patterns of connectivity» and that patterns of connectivity «may become active, or recede into latency, depending on actors' dispositions, objectives, and contexts of action» (Cardinale, Reggiani and Scazzieri 2022, 411). This means that the effectiveness of policy actions aimed at reducing the complex network's vulnerability and increasing its resilience to shocks critically depends on which connectivity pattern is prevailing in the network under consideration at any given time. An important consequence is that policies aimed at increasing network resilience should primarily identify what is the prevailing architecture of connectivity. Indeed, policies could even aim at promoting resilience-enhancing patterns of connectivity to make a network more resistant to ruptures and crises. An important route to network resilience is the consolidation of a hierarchic structure of connectivity in which relatively stable sub-networks at intermediate levels of aggregation (close to Herbert Simon's «stable intermediate forms», Simon 1962) enhance the resilience of the whole system. In this case, the existence of a “cascade” of stable forms at intermediate levels of aggregation may be an effective route to increasing overall network resilience.

The workshop held at the Bologna Academy of Sciences on June 6<sup>th</sup>, 2024, aimed at prompting an interdisciplinary discussion building on the themes of the NETS special issue. The workshop was structured around three research questions: what are the research perspectives on the architecture of complexity of socio-economic systems; what is the role of the architecture of connectivity in shaping complex subsystem-system dynamics in the socio-economic sphere; which contribution can be expected from a structural connectivity framework in shaping the design and implementation of policies.

The special issue editors introduced the workshop. Aura Reggiani examined the relationship between the architecture of complexity and the architecture of connectivity and emphasized the dual role of network centrality in increasing or reducing the vulnerability of networks depending on the characteristics of network hubs and on the dynamic paths by which connectivity spreads from hubs to the rest of each network. Roberto Scazzieri considered the relationship between the architecture of complex networks and network dynamics and emphasized the role of structural specification (the representation of the architecture of connectivity in networks) in addressing certain features of connectivity rather than others. He also examined the relationship between structural specification and the relative invariance of certain relationships in each network and maintained that different specifications of structure may emphasize certain invarianc-

es while neglecting others. This brings to light a link between structural specifications and the different dynamic paths that a network may follow depending on which features of structure are dominant. Ivano Cardinale concluded the introductory session by considering the relationship between how actors (such as policy makers) visualize the structure of connectivity in networks and the routes by which actors’ systemic or sub-systemic objectives may be pursued. He maintained that, in general, a given network is compatible with alternative visualizations of connectivity and that different architectures of connectivity may lead to the identification of different central actors and different affordances and constraints for those actors.

Session One, chaired by Bologna Academy Fellows Mirko Degli Esposti and Aura Reggiani, was devoted to organization and complexity in socio-economic networks. Professor Terry Friesz (Pennsylvania State University, US) delivered a keynote lecture on *Equilibrium Network Design: Resilience, Connectivity and Complexity*. In his presentation, Friesz examined the design of network infrastructures that take the form of roadmaps and asked the question of which network design would be most effective in achieving a systemic objective such as reduced traffic congestion. This lecture highlighted the distinction between topological network design aimed at achieving the systemic objective by direct means (such as modifying network infrastructure) and the design of indirect means (such as inducement mechanisms) influencing traffic flow patterns through drivers’ actions. The lecture emphasized the need to avoid local solutions endangering the achievement of the systemic objective (as when a solution diminishes congestion locally while increasing it globally). It also addressed means of reducing congestion by making use of resilience devices (such as calendars managing traffic flows) and connect- edness devices (such as inducement to use alternative routes). The following discussion called attention to the implications of a nonlinear objective function, the role of ‘good’ rather optimal solutions, the granular character of traffic, and the analytical difficulties of dealing with a multiplicity of dynamic (differential) equations in both continuous and discrete time in the study of optimal networks, as well as in the study of network (in)stability.

Session Two was devoted to the dynamics and architectures of connectivity. The session was chaired by Bologna Academy Fellows Luca Lambertini and Roberto Scazzieri. Professor Kieran P. Donaghy (Cornell University, US) delivered a keynote lecture on *A Circular Economy Model of Economic Growth with Circular and Cumulative Causation and Trade*. Donaghy outlined the principal features of a circular economy based on recycling and discussed ways in which cumulative causation can bring about an increasing returns trajectory helping to achieve a circular economy objective. This lecture emphasized the three principal sources of Circular Cumulative Causation (CCC) as: (i) increasing returns to scale; (ii) learning by doing; and (iii) human capital deepening, and examined ways of triggering CCC through global supply chains and international trade. Donaghy’s three-country model brings to light the feasibility of a CCC trajectory in which pollution decreases monotonically even as economic growth increases. The discussion following Donaghy’s lecture called attention to the role of consumption habits in mitigating pollution (for example by countering the planned obsolescence and low quality of consumer goods), to the role of limited substitutability of productive factors, to the extent that patterns of connectivity may trigger certain trajectories of increasing returns rather than others. The discussion also highlighted the role of intermediate levels of aggregation along CCC tra-



jectories, the relevance of space in cumulative causation and circularity, and the insights from research in the structural dynamics tradition that examined the possible integration of increasing and decreasing returns along trajectories triggered by the scarcity of non-producible inputs.

Session Three was devoted to policy making in a structural complexity framework. The session was chaired by Bologna Academy Fellow Patrizio Bianchi and by Ivano Cardinale. Patrizio Bianchi introduced the session by emphasizing the role of policy in generating networks aimed at the achievement of collective objectives. Bianchi also emphasized the dynamic character of network construction in the sense that networks are living organisms for which there is neither initial nor final state. As in Adam Smith's analysis of the relationship between labour specialization and integration of capabilities in a coherent system, connectivity provides means by which policy makers can have an active role in triggering complementarities of specializations in view of systemic objectives. Dr. Ariel Wirkierman (Research Unit in Structural Economic Analysis, Goldsmiths, University of London) delivered a keynote lecture on *Leontief meets Markov: Sector Vulnerabilities and Policy Implications*. This lecture emphasized the role of connectivity architecture (as expressed by a structure of Leontief input-output relationships) in providing information concerning the likelihood and timing of propagation of dynamic impulses along the supply chains of a production network. In this regard, Wirkierman considered network centrality as key to identifying propagation routes, and transversality across sectors as a random walk measuring the vulnerability of the economy (in the sense of linking vulnerability with how long it may take to go from one node to another within the existing network). This framework suggests that the singularity of central nodes may increase the vulnerability of a production network, that final sectors may be more important than intermediate sectors in addressing vulnerability, and that a concentrated export structure makes an economy less capable of maintaining/reintroducing a replicable circular flow relatively to an economy in which the export structure is less concentrated. The lecture concluded with an empirical assessment of centrality, export structure, and vulnerability from a cross-country perspective. The discussion that followed Wirkierman's lecture emphasized the need to consider all feasible paths within production networks and addressed the question of whether and how increasing complexity may influence the vulnerability of the economy.

The final session was chaired by Bologna Academy Fellow Carlo D'Adda. Professor Alberto Quadrio Curzio, Bologna Academy Fellow and President Emeritus of Accademia Nazionale dei Lincei delivered the concluding address emphasizing the role of the "control of theory" in considering empirical and policy issues. From this point of view, Quadrio Curzio called attention to complexity analysis as an essential route to the study of the structural evolution of economic systems, especially given the discontinuities characterizing structural dynamics and the time taken by periods of transition (partly due to the links between change of technology and transformation of resource base). Quadrio Curzio also emphasized the role of scientific and technological platforms (such as CERN and the European Molecular Biology Laboratory, EMBL) as nodes of knowledge networks that may be of critical importance in overcoming technological scarcity and facilitating the transition from one production network to another. Carlo D'Adda and Aura Reggiani concluded the workshop. Carlo D'Adda emphasized the links between the dynamics of production networks and that of organizations and institutions and

highlighted in that respect the role of interdisciplinary research and education. Aura Reggiani emphasized that the dynamic visualization of networks had been a central theme running across the workshop proceedings, together with the awareness that links can be disrupted, and that the distinction between weak and strong links at multiple layers of connectivity can provide a route to resilience along paths of structural transformation.

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