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Complexity Economics as Heterodoxy: Theory and Policy

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Abstract: Complexity economics has quickly become a powerful research program for real-world economics in recent years. This article provides an overview of complexity economics, and argues that it is incompatible with the "equilibrium" and "optimality" conceptions of the mainstream and its "market economy." Instead, it develops older heterodox — including evolutionary-institutional — issues like self-organization, emergence, path-dependence, idiosyncrasies, lock-ins, or skewed power distributions. Also, the space for emergent institutions through the "intentionality" of agents, including their improving collective performance, reducing complexity, and others, is investigated. This article considers complex adaptive systems through "games on networks" in an "evolution-of-cooperation" perspective. Moreover, a surge in policy implications of economic complexity has emerged, even if still rather general. With some more specific implications derived, the article again reveals the close similarities with long-standing heterodoxies: namely, pragmatist policy conceptions in this respect.

Keywords: complex adaptive systems, economic policy, futurity, institutional emergence, interactive/institutional policy, meritorics, network topologies, pragmatist policy, repeated social-dilemma games/evolution of cooperation, self-organization

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"Mainstream" policy conceptions and practice — propagated less in economic research papers than in textbooks, applied funded expertise, mass media statements, or public economic-policy advice — have been more normative prescriptions for a "state planning for more market" (basically just a "deregulation *cum* privatization") rather than sets of conditional recommendations based on considerations of alternative system potentialities and pathways. Such crude *normativity*, having now dominated the

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world for four decades, is usually not put forth overtly, but *tacitly*, due to an attitude of "t-i-n-a" (i.e., Margaret Thatcher's infamous "there is no alternative").

Simplistic and Complex Systems and Policies

The economic conception behind the t-i-n-a worldview is the idea of some (unique, optimal) equilibrium benchmark (a point or a path), connected to a "perfect" "market" economy as derived from a rather simplistic basic type of economic model. This approach usually allows for analytically tractable, deterministic solutions, with its "perfect representative agents," determinable "optimal" decisions, and thus predetermined equilibrium[1] — a *teleological* attitude that Thorstein Veblen criticized (for more on that, e.g., Fontana 2010; Foster 2005, 2006; van den Berg 2016).

Stochastic versions of this approach, such as the dynamic stochastic general equilibrium (DSGE) macro-models, usually presume *random* stochastic processes (tracing back to the idea of the "Brownian motion" of blossom pollen on the surface of a fluid, to be considered random). Related statistical value and event-size distributions then are considered *normal distributions* (of components' properties, events, and system motions). In turn, "rational expectations" of clear-cut (and existing) mean values and calculable risk reflected by comfortable variances can be justified (for more, see also, e.g., Gallegati and Kirman 2012). This way of thinking, however, may only be warranted in the so-called *non-organized complex systems* (Weaver 1948): that is, systems with a large number of identical particles, whose motions can be assumed to average each other out, as in the early nineteenth-century physics' view of a gas in a container under static conditions (or botanist Robert Brown's pollen on water above).

These presumptions have also been used for general economic models, and financial sector models pre-2008, which, however, are not "non-organized" systems at all. Such simplistic models, as it turned out, became a cornerstone of the great financial crisis of 2008, because financial systems and real-world economic systems in general — with their human agents that interact systematically (in ways to be determined below), following rules, as well as anticipate and adapt to new conditions in many ways and in many overlapping arenas — are precisely systems with *organized complexity* (Weaver 1948).[2] These systems display organized complexity because they behave qualitatively different from random motions (e.g., Battiston et al. 2015; Lux and Marchesi 1999; Mandelbrot 1997; Mandelbrot and Hudson 2006; Tang and Chen 2015) — based on what today is known as *self-organization* mechanisms. Such

[1] Whether this serves as an actual model outcome or as a normative welfare benchmark.

[2] This older terminology makes it clear, as a reviewer noted, that modern complexity economics is in the traditions of general systems theory (von Bertalanffy 1968) or cybernetics/systems control (Norbert Wiener, W. Ross Ashby; this also relates to a systemic policy, and I make a reference to it in the policy section below), as well as to sociological systems theory (Niklas Luhmann). In economics, for instance, some of the more stringent thinking German ordoliberals might also be considered as thinking in systems and connected to older systems theory. (For a more comprehensive view on complexity in a history of economic thought perspective, see, e.g., Elsner, Heinrich and Schwardt 2015, ch. 12).

self-organization capacities of "(self-)organized" systems have justified — particularly along Hayekian lines — the redudantization of any proactive policy, as such systems' properties have been theorized (under the heroic assumption of a favorable information distribution) to generate some relatively "optimal" (and "natural") "spontaneous order" (even for the financial sector, this claim was recently made; see Lewin 2014, among others). If one drops the presumptions of such a favorable (random) information distribution among agents, it becomes obvious that such self-organization capacities boil down to nothing else than just *any* kind of *systematic* reactions of agents to each other: appropriate or not, problem-solving or "ceremonial," "good" or "bad," cooperating for the common good, or striving for invidious distinction, emulation, relative status, and power.[3]

Such self-organization mechanisms do exist in surprisingly many different systems: from molecules, genes, and cells under certain environmental conditions, to sand piles and snow avalanches, from tectonic plates to human languages, territorial settlements, firm populations, and human agents' economic interactions in general. Particularly, as economies are open metabolic systems, self-organization may generate persistent "dissipative structures," i.e., some *order*, and the system may increase its complexity at the expense of their environment and an overall increasing entropy — all far beyond any optimality or unique, predetermined equilibrium (on the so-called "dissipative structures" or systems, see the chemo-physical classic by Prigogine and Nicolis 1967; for emerging complex structures in the interaction process of systems in general, see the bio-genetic classic by Kauffman 1993; for metabolic economic systems and economic complexity vs. sustainability in an institutionalist perspective, see Valentinov and Chatalova 2016).

In fact, *complex adaptive systems* (CAS) usually display dynamics with often abrupt transitions between some temporary order and volatile disorder, stasis alternating with turbulence and transition (more on economic CAS, e.g., Bloch and Metcalfe 2011; Durlauf 2012). Thus, even some self-organized "order" is very relative and has little to do with equilibrium, "optimality," "amelioration" or a "natural" state. The need for *policy*, therefore, which shapes and influences CAS and their dynamics "for the better" or reduces volatility, opacity, and over-turbulence as perceived by individual agents, comes into play and has a qualitatively greater (though completely different) role to play than in a simplistic model world. As David Colander and Roland Kupers (2014, 5) argue, "seeing the social system as a complex evolutionary system is quite different from seeing it as a self-steering system requiring the government to play no role, as seems to be suggested by unsophisticated market advocates." In other words, self-organization does not release us from public policy.

Particularly in decentralized (and deregulated) spontaneous individualistic economic systems — usually called *"market" economies*, with their particular volatilities,

[3] A reviewer made the important notice that "self-organization" thus falls behind the important distinction that institutionalism already had introduced: problem-solving vs. problem-aggravating self-organization, which allowed institutionalism to develop a particularly critical theory. This distinction is indeed a central motivation for and crucial throughout this article.

turbulence, perceived (over-)complexity, and incentive structures often in favor of a myopic culture (e.g., Aspara et al. 2014) — "self-organization" mechanisms tend to dominate in such ways that generate *fallacies of aggregation* in ubiquitous, more or less, intricate decision-making structures (such as social dilemmas, see also, for example, Valentinov and Chatalova 2016), and a "pervasiveness of *negative unintended consequences*" (Wilson 2014, 12, emphasis added) will result — and often cumulative, positive feedbacks tend to shift the system toward a *lock-in* in inferior states (e.g., Arthur 1989; David 1985). All in all, they generate anything but predetermined optimal/natural equilibrium. This reflects information deficiencies, cumulative reactive behaviors, or power-related, "ceremonial" degenerations of institutional behavior, in addition to cumulative technological processes like increasing returns in production or network externalities in use. Deregulated and globalized "markets" indeed tend to generate some (perceived) over-complexity (of the individual decision situation) and turbulence, with its increasing opacity for individual agents and currently well-investigated systemic costs (e.g., Battiston et al. 2015; Helbing 2013), thus unsurprisingly *restricting innovation* capacities and progressive innovation willingness of individual agents in broad cultural arrays (e.g., Vega-Redondo 2013).

Against this background, *complexity economics* (CE)[4,5] suggests that, although self-organization mechanisms might sometimes shift a CAS into a unique dominant stationary state (some stable attractor, be it "good" or "bad," superior or inferior), they usually will give rise to different *multiple equilibria* (superior and inferior ones), all of them usually unstable and transient. In decentralized, deregulated spontaneous individualistic economic systems ("market economies"), a problem-solving self-organization — namely, some "instrumental" *institutional emergence* — required to provide a stable and superior attractor through behavioral habituation, may be: (i) very time-consuming to come into effect and (ii) fragile (prone to backslide), if not (iii) entirely blocked (details below). Some system(at)ic policy vis-á-vis real-world economic CAS thus seems to be strongly warranted. Properly elaborated *complex adaptive policies*, particularly when focusing on proper institutions and institutional change, then may help improving incentive structures and other critical factors of agents' behaviors (details below), thus supporting emergent social behavioral rules.[6] They may, for instance, promote collective problem-solving capacities, stabilize the system's path, make it settle in a superior attractor area, and generally improve its properties and dynamics (e.g., Gilles, Lazarova and Ruys 2015; Hu, Lin and Cui 2015; Peneder 2017)

[4] For example, Mitchell Waldrop (1992); Brian Arthur, Steven Durlauf, and David Lane (1997); Vela Velupillai (2005); John Foster (2005, 2006); Elizabeth Garnsey and James McGlade (2006); John Miller and Scott Page (2007); Eric Beinhocker (2007); Melanie Mitchell (2009); Alan Kirman (2011); David Colander, Richard Holt, and J. Barkley Rosser (2011); Masahiko Aoki et al. (2012); and Brian Arthur (2013, 2015).

[5] There are many definitions and measures of complexity based on, for example, how difficult a CAS is to be described or reproduced in terms of computational time or information bits (for an overview, see Lloyd 2001). I will not confine myself to a particular definition, but will focus on describing broad complexity properties.

[6] I refer to social rules as solving relatively simple coordination problems (mirrored as coordination games), while social institutions solve more intricate social problems (dilemma games) (details below).

— although, as Alan Kirman (2016) stresses, those basins of attraction, where systems often lock in (for shorter or longer periods), themselves change with the evolution of the system and in particular with structural policy intervention, which in turn requires a proper policy toward CAS to become even more informed, analytical, forward-looking, and sophisticated (details below).

However, this will not be any rampant interventionism, and no Hayekian "road to serfdom." On the contrary, strong and reliable, long-term and adaptive systemic policies may avoid cumulatively increasing *ad hoc* interventionism, as has been the paradox consequence of the increasingly crisis-prone neoliberal era, of its privatization and deregulation and subsequent interventionism to stabilize and bail out. On the *theory* side, therefore, it has become increasingly obvious, particularly since the great financial crisis, that the economy needs different theories and models than those based on perfectly informed hyper-rational agents, "smooth" random process, and predetermined (stochastic) equilibrium, propagating simple "market" apologetics. Note that a great number of economists, who still consider themselves "mainstream," in fact have turned to CE, how hard they ever try to reconcile their complex research results with conventional "market" enthusiasm.[7] In what follows, I argue that CE is actually incompatible with the historical message of the economic "mainstream" that the "market" economy tends toward a general, stable, and optimal equilibrium, and thus is the vanishing point and end of human history, but that CE is rather consistent with most issues of the different heterodoxies, providing them with analytics that may even help them to converge (such efforts are being increasingly made recently, at last, by heterodox economists, such as Davis 2007; Robert, Yoguel, Lerena 2017; Thornton 2016).

Complex models, reflecting an even more complex reality, consider many and heterogeneous agents in recurring direct interactions within many different and problematic incentive structures and with many self-organization mechanisms. Distinguishing between CAS that are "adaptive as systems" and those that are "composed of agents that employ adaptive strategies" (Wilson 2014, 3), I will deal with the second group. While evolutionary macro-models with aggregate entities and without (or only with representative) micro-agents, belong to the first type, CAS with a large number of agents, who interact, adapt, and learn, belong to the second subgroup (e.g., Holland 2006). On the *methodology* side, complex models can only be applied eventually as *agent-based* models (ABM) and interactions on network topologies (e.g., Gallegati and Kirman 2012; Wallace 2017). Such models generally are no longer analytically solvable, and can only be computed in complex simulations. Therefore, they demonstrate that the economy usually deals with completely different problems than predetermined unique, stationary equilibrium, optimality, etc. — a *paradigm shift* indeed (e.g., Arthur 2015; Davis 2017; Fontana 2010). In fact, CE takes

[7] Beyond such ubiquitous reinterpretation in favor of a "superior market economy," and related flaws and schizophrenia in the dominating mainstream research and statements, Steven Durlauf (1997, 2012) from Santa Fé Institute, for instance, even considers CE to be largely consistent with the neoclassical mainstream. But, of course, he has to drop the claim of a "perfect market economy."

up most of the long-standing heterodox questions, issues, and theories. I strive to show that, with its cutting-edge models and computation tools, its systemic and "mechanismic" (Mario Bunge) character, and its new perspective on mutual micro-macro-foundations, CE has developed into a promising paradigm that has the potential to serve as a research program bringing current heterodoxies into closer interaction (also, e.g., Elsner 2013, 2017).

On the *policy* side, implications of CE have become a major theme recently, naturally occurring with some time lag vis-à-vis its underlying research program (i.e., CE), and particularly boosted by the great financial crisis.[8] However, much of this literature (with exemptions) still is rather general and has rarely developed policy implications from a model basis yet. In this article, I refer to a well-known group of CAS — namely, the evolution-of-cooperation tradition — with its multiple strategies for repeated social dilemmas in an evolutionary game-theoretic (EGT) perspective and an evolutionary-institutional interpretation (Axelrod [1984] 2006; Kendall and Chong 2007; Lindgren 1997; see also Colander and Kupers 2014), in order to derive some more specific policy orientations. However, I do abstain from developing particular policy cases, such as a more appropriate (i.e. complex) innovation policy or a financial sector reform, for lack of space. I will argue rather that emerging policy conceptions of political experimentation, adaptation, learning, institutional focus, and framing of particular interaction conditions of the private individual agents, display surprising similarities with the long-standing *pragmatist/instrumentalist understanding* of society and policy in the evolutionary-institutional tradition (and Keynesian tradition as well).

In the next section, I briefly review CAS, with its structures, mechanisms, critical factors, and system properties, and indicate its affinity with economic heterodoxy. In the third section, I consider some complex adaptive policy orientations from the literature. In the fourth and fifth sections, I refer to the "evolution-of-cooperation" approach and its policy implications, and generalize policy implications derived from an evolutionary-institutional interpretation of games on networks, also considering dynamic populations with ever-changing "fitness" conditions, demonstrating that there is no space for any "natural," endogenous, "ameliorative" tendency. In the sixth section, I clarify that complexity policy cannot circumvent socio-political evaluation, introducing the idea of a "new meritorics," coinciding with the long-standing pragmatist/instrumentalist policy conception. In the final section, I offer my conclusions.

[8] For example, Durlauf (1997, 2012); F. Gregory Hayden (2006); Salzano and Colander (2007); OECD (2009, 2017); Robert Geyer and Samir Rihani (2010); Graham Room (2011); Magda Fontana (2012); Göktu Morçöl (2012); Tony Dolphin and David Nash (2012); David Wilson and John Gowdy (2013); Colander and Kupers (2014); Magda Fontana and Pietro Terna (2015); Robert Geyer and Paul Cairney (2015); and Jim Price et al. (2015).

Theory: A Brief Resume of Structures, Mechanisms, and Dynamic Properties of CAS and Their Heterodox Potential

I make a logical distinction in the following among antecedences (initial, "given" structures), process outcomes (emergent structure, resulting system properties), and continuing feedback (differential replication, endogenizing structures) of CAS. Particularly, emergence vs. ongoing evolution and change is an often used analytical distinction for complex systems.

Initial, "Given" Structure

In CAS with a population of (many and heterogeneous) interacting agents, usually on some initially defined network topology and often with games played on graphs, model structures (or components) that are considered as given include:

Decision structures: Multiple and (potentially) heterogeneous agents (with different behavioral/strategic options, of which different may be interactively learned by different agents) are directly interdependent and recurrently interacting in different, more or less, "intricate" social interaction problems (incentive structures, usually between two agents each). The usual formal language for this is game theory. One may think of different coordination, anti-coordination, non-(or dis-)coordination (e.g., zero-sum), and social-dilemma games. Different behavioral options, under indefinite recurrence, then generate (initial) fundamental strategic uncertainty and open room for search and experimentation and the learning of different social rules and institutions.[9] Such learned rules and institutions may (and often must) become habituated and then emerge under reinforcement learning, and a learned and culturally acquired longer time horizon may substitute the initial "market" myopia (details below). Other conditions of cognition, information, and expectation (such as the quantitative incentive structure or interaction-arena size) and other agency capacities (such as partner selection) may also help. In addition to the game type, specific incentive structures and the *size* of the interaction arena, as well as certain institutional structures, (e.g., some basic "rules of the game") must be considered as a "given."

Network structures: These interdependence structures (game types, incentive structures, indefinite recurrence, and other conditions mentioned) also may be defined on different network topologies:[10,11] a population with different social or

[9] See Footnote 6. As "coordination" and "cooperation" are solutions of coordination games and dilemma games, respectively, so do the solution tools, "social rules," and "social institutions," refer to coordination games and dilemma games (for the definitions, see Elsner 2012; Schotter 1981).

[10] Games on networks are a particularly fast growing research area (see Jackson and Zenou 2015).

[11] Note that I call the given (and later endogenous) topology of a whole population a network topology, possibly consisting of many neighborhoods and interaction arenas, and I also term an emerged spatial form of multilateral institutionalized cooperation, emerging out of one arena (e.g., a particular evolving neighborhood or a firm cluster) a network.

geographical distances/proximities (defining "neighborhoods," reference groups, etc.), with related differential probabilities to interact, and implications for different acquired information and experience, thus for different behavior, strategy and performance (a classic neighborhood model, with some unintended segregation outcome is Schelling 1971). Different received (given) structures have implications for different dynamics, for ways and speeds of information or behavior diffusion, or for systemic risk and stability (e.g., Acemoglu et al. 2012; Acemoglu, Ozdaglar and Tahbaz-Salehi 2015; Jun and Sethi 2007; Ormerod 2012). Empirically relevant network structures are typically not "complete networks." That is, they have no full connectivity (whereby agents would interact with each other with equal probability in any given time period), but usually display different spatial centrality, clustering, and distance patterns. "Neighborhoods," for instance, may be clusters or subnetworks within a larger network topology of a population. There also may be overlapping and staged systems of clusters or subnetworks, where one agent may interact with the same or different agents in different arenas, in different social roles, and for different "goods" (each with different and overlapping reaches, or at different stages). Furthermore, agents may die, be born, learn and change strategies, as well as imitate or occupy certain behavioral niches in response to their relative success. When agents are allowed to move within the topology in reaction to their relative performances, such network (neighborhood, cluster, arena) topology will become endogenous.

Institutional structures and "rules of the game": Initial structures are assumptions in a modeling process. Initially given behavioral options (strategies), interdependence structures and network structures are not preset "givens" in reality, but they are always the evolved results of preceding historical processes. While even the "rules of a game" (e.g., periodization of interactions, mutual rationality assumptions and other common knowledge, common time horizon, correct understandability of actions, etc.) may have to be considered part of what needs to be explained as emergent structure, they mostly also are methodologically required givens (which, of course, requires particular awareness in modeling).

Process, Emergent Structure, and Resulting System Properties

Continuing interaction, nonlinear aggregation, and structural emergence: As I already indicated, ongoing interactions of the system's components — be it explicitly modeled intentional, responsive, learning and adaptive agents, or just strategies and their assumed carrier groups in conventional EGT — generate (under simple conditions already) some cumulation and thus nonlinear aggregation, compared to no interaction and thus static ("linear") summing up (e.g., of the supply or demand quantities of representative agents). In agent-based systems, broadly speaking, agents will adapt to each other, to their neighborhoods, and sometimes to the global state of the system. They may imitate others or individually exploit given circumstances like all others, give positive feedback to others, or cumulate in other ways. With such non-linearities, emergent (macro-) structures cannot be reduced (traced back) to the individual properties and behaviors of the agents — the well-known phenomenon of emergence.[12]

Emergent meso- and macro-properties: Emergent structures also show that boundaries between micro and macro blur and "micro-foundations," in fact, work differently from the simplistic mainstream conception of them. Emergent macro-structures then feedback (e.g., through institutionalized behavior or any action based on global information) to micro-behavior, and may change it (a "reconstitutive downward causation," see Hodgson 2002). And when it comes to a complex, circular and evolving process with ongoing emergent structure and reconstitutive downward feedback, the limits of analytical tractability and determinacy are quickly touched. Empirical stochastic analyses of system behaviors (of real-world or artificial systems) may relate to both (macro-)system structures and their (micro-)link level (e.g., Acemoglu, Ozdaglar and Tahbaz-Salehi 2015; Jackson, Rogers and Zenou 2015). Resulting distributional properties and distributional statistics of the system, for instance, may indicate both micro- and macro-properties. Often, it is also appropriate to focus on some meso-level, which is considered below the size of the entire population, since informal structural emergence usually occurs at "mid-sized" interaction arenas, due to more appropriate cognitive and expectational conditions existing there for humans, their interaction process, and their cultural emergence (e.g., Elsner and Heinrich 2009; Elsner and Schwardt 2014).

Path-dependence and non-ergodicity: CAS, therefore, are recursive not only among their components, but also among their micro-, meso-, and macro-levels. Agents act under complex conditions (many interactions with many heterogeneous agents and in ever-changing socio-ecologies), with relatively limited cognitive capacities, mostly with the only valid experience being local, and with fundamental uncertainty (bounded rationality), while searching, experimenting, reacting and adapting. As a result, the system will behave non-regularly, *statistically non-stationary* over time, or in path-dependent ways.[13] This may be consistent with the settling of the system (for some time) in some (unstable) fixed point or (transient) attractor,[14] or its traversing of some periodic orbit. Path-dependent processes, as is well-known, are sensitive to initial conditions and are often vulnerable to small changes of conditions. In this sense, "history matters" — and it matters extremely so in the "chaotic" case,

[12] Note the terms equivalent to emergence in the tradition of systems theory: namely, morphogenesis and autopoiesis (Luhmann). System capacities of emergence are considered *the* distinctive property of complexity sciences, thus termed "generative sciences" (after Joshua Epstein and Robert Axtell 1996; see also Harper and Lewis 2012).

[13] This logically requires that system variables are time-dependent in themselves and among each other (discretionary: $x_{t+1}=f(x_t, y_t)$ and $y_{t+1}=g(y_t, x_t)$. Interestingly, but comprehensibly, path-dependence was taken seriously earliest in agricultural economics, as a reviewer explained.

[14] Again, note terminological equivalences: The phenomena of an attractor and or a meta-attractor, where a system repeatedly will settle, called self-organized criticality (below), were, in substance, known as emergent system properties to earlier systems theory, such as equifinality (von Bertalanffy 1968), homeostasis, or (in natural and ecological sciences) resilience.

whereby, at a "tipping point," one cannot statistically predict exactly enough and in the short run, where the system will go to. Furthermore, the infinite recurrence and sequentiality of interactions as well as the infinite differential replication of certain characteristics (behaviors/strategies) in the population will generate an "open-ended" process over real (historical) time (infinite or indefinite in time and usually unpredictable in substance, particularly in the short run). Such a process is mostly cumulative and always irreversible, and sometimes becomes highly *idiosyncratic* (i.e., *unpredictable*), as there exist multiple potential equilibria and paths. As I mentioned above, in the extreme idiosyncratic case, it becomes (in so-called phase transitions at so-called tipping points) "deterministically chaotic" (where the "tipping point" as such and potential future alternatives may be determinable, but the exact following motion cannot). Such path-dependent systems are also *non-ergodic* in the sense that the distribution of states that they assume over time is not identical with the distribution of potential states they basically could assume (as judged based on their structure). Thus, again, no normal distribution of the occurrence of certain events (motions) with simple probabilities for their forecasting exists, but a highly sensitive dependence on initial conditions.[15,16]

Self-organization and persistent fat-tail distributions: Self-organization capacities of interacting components (agents) on network topologies in CAS are reflected by empirically recognizable indications of emergent structure (in both real-world and synthetic systems), in particular, surprisingly persistent distributions of

[15] Such *non-ergodicity* is certainly one of the most difficult properties of CAS, and has been extensively discussed in the complexity sciences. So, it warrants some extra consideration (I owe this idea to suggestions of a reviewer and the JEI editor). In economics, the idea, conception, and axiom of (non-)ergodicity were adapted from statistical physics and the stochastic processes of physical systems (namely, dynamics of gases under different pressure and temperature). Post-Keynesians, for instance, have long discussed the issue in connection with John Maynard Keynes's conception of *fundamental uncertainty* and in delimitation of the rational-expectations justification of non-intervention of the state into the "market" (see already Davidson 1982–1983). More recently, there was a dispute about whether Keynes, in his critique of Jan Tinbergen and early econometrics (with Keynes's argument of "non-homogeneity" of data series, i.e., "non-stationarity" of stochastic process), already had an understanding of the non-ergodicity of complex economic systems (Davidson 2015; O'Donnell 2014). In a historical reconstruction of the development of the (non-) ergodicity theorem, J. Barkley Rosser (2015–2016) has recently investigated the "complex" relations among data "(non-)homogeneity," stochastic (non-)stationarity, and systemic (non-)ergodicity, showing, among others, that complex non-ergodic systems must display "inhomogeneous" times series for its properties, but may be stationary in some cases (as, e.g., in a periodic cyclical orbit, a so-called "limit cycle").

[16] I should also note that there is a mathematical, anthropological, biological, neuro-physiological, and game-theoretic literature on the variability of individual strategic behavior (human *proteanism*), the impacts of surprising hostility, negation, deceit, lying, and the related *surprise* in interactions (reflected, e.g., in anti-coordination games), discussing possibilities of the existence of Nash equilibria with surprise, the computability of absolute *novelty*, and the causes of fundamentally innovative behavior. This strand includes contributions of Kurt Gödel, John von Neumann, Alan Turing (all in the 1930–1940s), and, more recently, Benoît Mandelbrot, Ken Binmore, J. Barkley Rosser, and Philip Mirowski. Mathematically, computationally, and in neuroscience, this refers to (the human capacities of) complex recursions (between an adversarial other and the self). I will not delve into this here, and confine myself to the nexus of such *rare events*, surprise, and fundamental uncertainty with the property of idiosyncrasy and non-ergodicity. I also refer to my remarks on Frank Knight and G.L.S. Shackle on surprise and *creative decision*, and some policy implications further below (for a recent overview, see Markose 2016).

certain properties (e.g., centralities of agents or critical system motions). For instance, certain persistent centrality distributions among agents in a network may emerge, or some dominant attractor may cause repeated system motions (again, of a certain size distribution) back toward itself after a shock. I am referring here to self-organization processes that generate non-normally distributed, but *right-skewed statistical distributions of agents' centrality positions* and of the related sizes of critical events and motions (such as system crises). Self-organization processes are no random processes and do prevent normal distributions of centrality and of system motions. In decentralized and spontaneous systems ("markets"), in particular, self-organization processes lead to right-skewed (long-tail or fat-tail) distributions. Usually, there are many agents with only a few relations (low centrality) in a network/system, and only a few agents with many relations (high centrality). The *self-organization mechanisms* at work here have been considered as *the rich get richer* (Barabási and Albert 1999). The problems of those most central (and powerful) may then cause much *larger crises* of the system (occurring with a considerably higher probability than in a normal distribution) than problems of an average agent. Of particular interest here have been those extreme self-organization mechanisms that are so strict across the whole population that they display the same functional property at all levels. The resulting persistent functional form of the related statistical distributions, as detected first by Vilfredo Pareto for income distributions across countries and centuries, has been termed *power-law* distributions, which have the same functional properties at all scales, indicating a strong self-organization mechanism, working identically at different scaling (the phenomenon of *self-similarity* or *scale-free*-ness, with repeating patterns at different scales, equivalent to so-called "fractal" sets). Mapped as log-log, this generates a linear curve, making it obvious that such distributions are identical to themselves at all levels. In many real-world *spontaneous decentralized systems* on spatial and/or social topologies — usually based on historically emerged, deep-rooted *individualist cultures* — agents and organizations differentiate (in particular sequences of action and reaction) in terms of *power and status*. Social network analysis (SNA) and network statistics over time then usually reveal such long-tail or even power-law distributions of centrality degrees. These show up in many and diverse real-world areas, such as income and wealth, *firm size* ("Gibrat's law") or spatial settlement systems (towns and cities, "Zipf's law"), the distribution of internet sites by visits, but also letter and word frequencies in languages, nodes in brain structures, the size distribution of natural forest patches (and related forest fires), of sand-pile or snow avalanches or of earthquakes, etc. Some self-organization may even lead to a certain size distribution of critical events (i.e., sudden movements), which repeatedly makes the system approach a certain critical state: a dominant or meta-attractor, where the continuous change of conditions after some major motion (a crisis, avalanche, etc.) itself contributes to a repeated system motion toward that attractor, a so-called *self-organized criticality*.[17] Note that this also applies to capitalist crises in general and to financial sector crises in particular. If the

[17] See the famous sand-pile model of the power-law size distribution of avalanches, when sand is continually dribbled onto a pile, as the prototypical formal analysis (Bak, Tang and Wiesenfeld 1987).

system is left as it was, the crises may *endogenously* reconstitute conditions (such as firm concentration, over-accumulation of capital, re-accumulation of sequences of securitized structured papers, etc.), under which the system will again build up toward the next crisis. Note that, in contrast to normal distributions, fat-tail or power-law distributions usually have no (or no finite) mean, around which "rational" expectations (of prices, events, etc.) can center. Thus, big financial crises, for example, occur considerably more often than could be expected in mainstream models of random process and "normal" distribution (e.g., Mandelbrot and Hudson 2006; Taleb 2007). Such repeated cumulation and crisis-proneness of social systems also has been a long-standing issue of original *evolutionary-institutional economics*. The mechanism of *emulation* of the higher social classes — and the invidious distinction among those of the same social class, operating at all social strata of received predatory societies — was central from the very foundation of institutionalism by Veblen (1899). Such "ceremonial" self-organization would then *trickle-down* through the entire society, and somehow homogenize the socio-economy, weakening its longer-run resilience and sustainability.

Emergent scale-free and small-world networks: Topologies that display such power-law distributions of nodes ("scale-free networks," see Barabási and Albert 1999) typically display some hierarchical structure of its sub-graphs, often hub-and-spoke type sub-networks. The more effective networks make specific use of central positions. They combine local clusters and central nodes with their long-distance relations in specific ways, so that central positions play some central role within local clusters, but mainly do so among the clusters, at the "gates," where long-distance relations to other clusters begin. By their very clustering, those so-called small-world networks (see Watts and Strogatz 1998) facilitate local problem-solving through dense interaction, learning, and institutionalization, and, at the same time, through their long-distance relations, these networks display a relatively low mean path-length between any two agents in the entire network, thereby ensuring relatively quick and effective long-distance exchange, diffusion of information, and learning (of panic, disease, etc. as well). Again, this all has little to do with optimality, as large nodes like powerful agents may still cause problems for the system's stability and resilience. Such central power positions ("hubs," "gate-keepers," etc.), if not avoidable as such, will need to be carefully controlled.

Lock-in, ceremonial dominance, and collective-action capacities: Socio-economic CAS, based as they are on more or less intricate incentive structures (e.g., stag-hunt, or social dilemma games), usually reflect mixed interests (partially consistent, partially conflicting) and entail lasting tensions among agents under recurrence. But even in relatively simple coordination problems (games), with Pareto-different solutions,[18] a *collective incapacity* to ensure longer-term optimal solutions may exist, and systems may run into technical and/or institutional lock-in (Arthur 1989; David 1985). If this is at an inferior technological and/or institutional coordination,

[18] Note that one can use the Pareto criterion only in the beginning, when one develops complex systems stepwise from simple model elements, such as normal-form games. Later, the criterion will become rather narrow, senseless, immeasurable, or otherwise inapplicable.

it is indicative of fundamental differences between individualistic and collective rationalities and solutions. *Institutional lock-in* may be an indication of some dominant ceremonial warrant, i.e., dominant aspirations for a differential status and power perpetuated that way. For instance, such institutional petrifaction, some degeneration of originally instrumental institutions, may be caused by a persistent unequal distribution of cooperative gains, when the more powerful profiteers stick to the old institution and the inferior losers still follow their old habits and identify with their superiors, and the short-run costs of more appropriate institutions are higher than its short-run gains (Bush 1987; Elsner 2012; Heinrich and Schwardt 2013). However, as long as proper behavioral strategies can be interactively learned and adapted as instrumental solutions of coordination, stag-hunt, or dilemma problems, the emergent structure may assume the form of problem-solving rules and institutions. In either case, social rules and institutions will function as *complexity-reducing* devices. Whether instrumentally or ceremonially warranted, the very reason for institutions to exist is to generate some systemic *stability* ("homeostasis," "equifinality," in the ceremonial case also as a "hysteresis"), independent of any optimality, ensuring some behavioral and expectational continuity and stabilization, some consistence with humans' cognitive capacities, and a reduction of their perceived over-turbulence. Under problem-solving or instrumental conditions, they will also generate some progressive innovation in a broad sense. And, again, it this shows that, and how, institutional-evolutionary heterodoxy applies to economic complexity.

Individual agent capacities, intentionality, and institutionalization: EGT-based evolution-of-cooperation approaches presume many sequential two-person games in a population, embedded in a logic that reveals which particular agency capacities are required — capacities beyond just a short-run maximization. For instance, in order to solve prisoners' dilemma supergames (PD-SG), agents must culturally acquire and coevolve longer-term perspectives (futurity). As behavioral innovators and initial cooperators in an otherwise defective social environment, agents must also (logically) be risk-taking and not envious, and they must have some capacities of memory, monitoring, and reputation-building (e.g., Elsner 2012). Moreover, agents must be able to engage in some preferential mixing (partner selection) or in establishing and terminating relations, possibly also in a spatial sense, i.e., moving into and out of neighborhoods. Furthermore, given bounded rationality in multi-agent/multi-strategy environments — where transparency and cognitive capacities may quickly become too small for agents to behave globally (perfectly) rational, and perceived complexity and volatility too high (e.g., Durlauf 2012) — agents must be considered both searching (experimenting, adapting), and endowed with some *intentionality* to improve their outcomes, in order to solve common or collective problems[19] and reduce the perceived complexity of their decision problems. This is where the emergence of social

[19] As I already indicated, a coordination game is solved in the immediate interest of individualistic agents through coordination by a social rule, which is just *common*, parallel behavior. By contrast, the more intricate social dilemma, with its dominant incentive to defect and exploit, requires cooperation: namely, coordination plus a sacrifice of the short-term maximum, through a social institution, which thus is a social rule plus an endogenous threat of sanctioning and falling back (embodied in a "provokable" or trigger strategy), hence a *collective* phenomenon.

rules and institutions comes in, and Veblen's instinct of workmanship or idle curiosity would easily apply as such motives and value warrants needed to explain why agents begin search, experimentation, and learning of institutionalized cooperation.

Differential Performance and Replication: Cumulation, Evolution, and Endogenizing Network Structure

Differential replication, attractors, and orbits: Agents (or strategies) in a population with repeated and randomly or preferentially pairwise encounters will perform differently after many interactions within a "round" (i.e. a supergame) and after many rounds played with many agents at the end of an (artificial) "generation." A replicator mechanism generating differential "offspring," according to the differential performance, will typically provide a next logical "generation" with a *different social ecology*, i.e., a changed strategy composition of the population. Thus, with continuing replication, one could generate a full-fledged evolutionary process (as in early prototypes, e.g., Axelrod [1984] 2006; Lindgren 1997, and many others). Under certain conditions (reflected in parameter constellations), replication processes may converge to one out of multiple possible fixed points. An analysis of dynamical systems then will show whether such equilibria are stable or unstable. If unstable, the system may perform cyclical (periodic) or even non-periodic orbits or some more or less recognizable (albeit complex), more or less complex behavior in between, but usually real-world systems (and properly parametrized synthetic systems) will perform some recognizable behavioral patterns that can fruitfully be analyzed. Systems may undergo abrupt and discontinuous change, even as a result of a continuous marginal change of some parameter, which happens at tipping points. And again, under some self-organized criticality, CAS may have a dominant attractor, such that their macroscopic behavior repeatedly displays phase transitions toward it.

Dynamic populations and size-dependent fitness: Evolutionary "optimality," in the sense of a survival of the fittest across changing social ecologies, will typically not occur. A related "efficient" selection for such a result would require structural stability, so that a selection mechanism would have enough time to ameliorate the system. However, this is typically not the condition of complex dynamic human populations (again, another older Veblenian insight that there are no automatic "ameliorative" tendencies in socio-economies as we know them). In particular, when "fitness" and population shares of different strategies are subject to cumulative first-mover advantages, or cumulative power acquisition, or, on the other hand, to some limits of growth (marginal returns decreasing with increasing population shares), situations of a survival of the first, survival of the "fattest," or survival of all (with possibly widely varying shares) may occur (e.g., Nowak 2006, ch. 2).

Circular upward and downward causation: The evolution of CAS is not just bottom-up structural emergence, but "reconstitutive downward causation" from an emerged structure onto the behavior of agents (shaping and reshaping incentive structures, socio-ecologies, and behavioral patterns of agents). This is a particular aspect in the overall explanation of system motions and dynamics (transitionary settlements, periodic/aperiodic orbits, etc.), as described. I separately mention cumulative causation as a mechanism, reflecting particular self-organization mechanisms in socio-economies, as it provides another instance of older, well-established and well-elaborated heterodox issues and theories. Circular cumulative (both upward and downward) feedbacks have been basic mechanisms known in evolutionary institutionalism from Thorstein Veblen through Gunnar Myrdal to Karl W. Kapp (e.g., Berger and Elsner 2007).

Endogenous network structure: Finally, in an agent-based model, after a "generation" ends with differential performances, agents may establish or terminate links or move into some other neighborhood. If that occurs, then the network structure will become "endogenous," as is well established in CE approaches and modeling (e.g., Jun and Sethi 2007; Berninghaus, Gueth and Schosser 2013).

With these basics of systemic structures, self-organization mechanisms, emergent structures, and resulting dynamic properties of socio-economic CAS (with some critical factors and processes already mentioned), the argument — as CE, its analyses, models, and theories — is finally "maturing to a point at which policy implications are emerging … Moving forward, it is our hope and expectation that … [this] will greatly aid in the understanding of policies" (Jackson, Rogers and Zenou 2015, 41).

Policy Orientations from Previous Complexity Literature

Against this background, there obviously exist non-optimalities and shortcomings of structures, mechanisms, processes, and emergent system properties in the socio-economies as we know them, resulting, for instance, in *over-complexity* and *over-turbulence*, as perceived by agents at least, given their cognitive and psychic capacities, and further, in inferior system states and dynamics (even inferior dominating attractors, repeatedly attained, repeated or lingering crises), and in related *social costs* (e.g., Helbing 2013; Mirowski 2013). All of these are not properly reflected by the mainstream theory of "market failure" (e.g., Fontana 2012) and its flawed simplistic policy implication (e.g., Peneder 2017). They require a more proactive, more systemic, "stronger," more adaptive, and longer-term policy strategy, in all, a more complex policy. Much has been developed already for such "complex adaptive policies" in the decade of the great financial crisis and recession.

"Revising the Concept of Regulation"

Complex structure and the resulting evolutionary process, for instance, suggest a very different conception of "regulation" than the economic mainstream established. As socio-biologist David Wilson argues (2014, 11), for a neoclassical and neoliberal economist, "regulation is something imposed by governments, and self-organizing processes such as the market are regarded as an absence of regulation," for a complexity scientist, on the other hand,

> all [?] of the metabolic processes that keep organisms alive and all of the social processes that coordinate … [social animals] are regulated … The concept of regulation in economics and public policy needs to be brought

> closer to the biological concept of regulation. The idea of no regulation should be regarded as patently absurd but determining the right kind of regulation and the role of formal government in regulatory processes are still central topics of inquiry. … [It is] clear that unmanaged cultural evolutionary processes are not going to solve the problems … at the scale and in the time that is required, which means that we must become "wise managers of evolutionary processes." (Wilson 2014, 11)

Then, "the selection of self-organizing regulatory processes" (Wilson 2014, 12) and their improvement becomes an overall policy task. In other words, if appropriate policies are not developed for the regulation of a CAS, the system would be regulated by an inferior self-organization mechanism — such as by the individualistic dynamics of the most central and powerful agents by herding, short-termism, etc.

Partly Endogenous Policy System

Public policy is a complex system itself with its own structural, procedural, and performative strengths and weaknesses, and with multiple and heterogeneous agents. When interacting with its target socio-economic CAS, the policy system has to have a certain minimum degree of complexity itself. Moreover, it is, at least partly, endogenous to the CAS under its scrutiny and control, as the policy system needs to be adapted according to the structures and evolutionary dynamics of the target CAS. Such endogenous control may cover a bandwidth of impacts from (i) an apparent non-reaction of the target system through some *policy evasion* of its agents, which prevents the system from properly reacting to policy measures, to (ii) a *hyper-reaction* in a way that the policy decision directly influences the target system in intended ways and is a Shackleian *crucial decision* (Shackle 1949), i.e., an intervention, which changes the very conditions, hence the mechanisms and dynamics of the target system, under which the original policy decision was made (similarly, as mentioned, by Kirman 2016). This twofold impact of case (iii) may include the intended effect, but also might counteract the intentions. In any case, the policy agent needs to take these ambivalent possibilities into account and consider the fact that the very *foundations* of its "crucial" decision-making may be altered through a "crucial" intervention. This is typically the case when *mechanisms* and *structures*, such as *institutional* (behavioral), *topological* (network), and *distributional* structures, are targeted and affected by policy intervention. With the proper consideration of all those levels of impact, and proper instrumentalization, policy intervention could be even more effective.[20]

[20] See footnote 16, where I address the relation between non-ergodicity and fundamental uncertainty. This relates to the occurrence of "rare," "unexpected," "surprising," "improbable," and "unique" events in a Knightian and Shackleian sense. While "imaginative" or fundamentally innovative crucial decisions, taken by private agents under fundamental uncertainty (certainly somehow institutionally shaped, similarly to Keynes's "animal spirits"), may contribute to the system's non-ergodicity (I owe this consideration to the JEI editor), this may also apply to the "crucial" measures of the policy agent, who may, intendedly or unintendedly, undermine the very conditions that were in place when the decision was made.

While complexity policy, as a structural and institutional policy, thus requires considerable systemic knowledge, foresight, and anticipation, it appears to be well-established in complex modeling, simulation, and experimentation that proper institutional design ("top-down") is feasible, can harness complexity, shape behavioral process, and attain targeted "bottom-up" process, emergent structure, network, and institutional change — something that the traditional literature on mechanism design, with its focus on equilibria, seems incapable of coping with (e.g., Clement and Puranam 2017; Page 2012). Again, it is obvious that targeted emerging institutions and network structures are path-dependent on the initial ones (e.g., Bednar, Jones-Rooy and Page 2015), and the policy system itself is thus path-dependently and endogenously involved and interconnected with its target CAS.

However, this does not mean that the policy system cannot keep itself sufficiently *exogenous* to and *independent* from the target system if it deliberately develops its different independent constitutional mechanism. Ideally, this will be then a unique, uniform, transparent, optimally (de-)centralized and public-participative discourse and decision-making, which are well-informed of the complexity and properties of the target system (and of its own required complexity). With this process in place, some *superior collective rationality* may become effective (e.g., Elsner 2001; Gilles, Lazarova and Ruys 2015) in "moving the economy from an undesirable basin of attraction to a more desirable one" (Colander and Kupers 2014, 53).[21] I will return to this idea below referring to the pragmatist policy perspective .

Higher Complexity for the Control System

An early insight from cybernetics and information theory was that the complexity of a control system needs to be at least as high as the complexity of the target system, according to Ashby's Law (Ashby 1956, 124-126), where "only [the] variety [of the control system] can absorb [the] variety [of the target system]." In order to shift a controlled system into an aimed-at area of outcome values, while dealing with often unpredictable adaptations of that system, the control system must be able to assume at least as many possible states (or, equivalently, to have at least as many degrees of freedom) as the controlled one, and be able to quickly adapt and appropriately react.

While this double impact involves the political control system further into the target system, making it even more intensely "*endogenous*," policy might become more effective when its instrumentation can make use of both dimensions of influence. This will usually be the case when it deliberately and systematically addresses and implements structural/institutional changes, thereby altering the conditions of individual human agency.

[21] As an example of methodological reflection of such endogeneity in an evolutionary-institutional framework, F. Gregory Hayden (2006) developed the social-fabric-matrix approach to investigate the network structure among agents, institutions, value systems, and the policy system, with input-output relations mapped as directed-graph systems. This approach has often been applied to policy issues and has helped pursuing policy impacts throughout the socio-economic system, with results that are often counterintuitive from a simplistic perspective. Again, institutionalism seems well prepared to deal with CAS and consistent with "complexity policies."

As it should have become clear by now, cause and effect of the target and control systems can no longer be considered simple, unidirectional, or structurally constant as in the simplistic model-policy world. For instance, a reversal of an earlier policy will usually not generate proportionate (symmetric) reverse effects in the target system. *Institutional collapse*, for instance, will typically not take place at the same parameter constellation where *institutional emergence* occurred. Nor will the strength of effects of identical measures be the same over time. In this way, "complexity policy" not only needs to be itself potentially more complex, but it also has to be system- and process-oriented, with a long-run learning and adaptation perspective — a "policy as a collective learning process" (Witt 2003). It needs to be prepared to assume different states for its interventions in pursuit of its objectives, and continuingly so. Note that most of the neoliberal governments have been dismantled after decades of neoliberal state-minimizing "reforms" to a degree that their action capacities and qualifications today are far from these requirements. Only few governments of very diverse mixed economies worldwide might pass the test of a learning adaptive policy. Scandinavia, Island, and China, among others (how one ever evaluates these countries), would come to mind. But this would be another analysis.

"Reducing Complexity"

Proper complexity reduction has been a major systems theory, CE, and complexity-policy issue. One has to distinguish between the complexity of the system and that of the decision situation of individual agents (compared to their limited cognitive capacity). The system may remain highly complex, while individuals' decision-making situations are made less complex (e.g., through some institutionalization). With respect to *system complexity*, many researchers have recently warned against increasing instability and uncontrollability under increasing (over-) complexity and (over-)*volatility* of globalized and financialized network systems (e.g., Helbing 2013; Mirowski 2013). Many argue that, to make this system manageable, a *fundamental redesign* (Helbing 2013) is needed. Ecological system theorists have combined perspectives from older systems theory and ecological economics, arguing that the current "market" economy as an open system, through its particular self-organization mechanisms, can increase its complexity and solve its tensions, inner conflicts, and problems only in the short-run and at the expense of (social and ecological) sustainability (e.g., Valentinov 2017).

One of the standard devices of reducing complexity since the early days of CE, as developed by Herbert Simon, has been a deliberate *modularization* into smaller and less complex subsystems (as already indicated in specific contexts above), considering that the *decomposability* of CAS usually is possible through their very historical emergence from more simple smaller systems (Simon 1962). According to Brian Loasby (2012), appropriate deliberate (re-)modularization of today's real-world (over-) complex CAS is to be based on a more *selective connectivity* (neighborhoods, clusters, smaller arenas, and staged arena systems, as well as partner selections), rather than further pursuing the ideal of a *globalized* total connectivity into anonymous, obscure, hyper-arenas. But modularization, or *delinkage*, which seems to be particularly urgent for the oversized, homogenized, "herding" financial sector (Mirowski 2013), must go together with proper *module or arena coupling* — that is, proper *small-world* structures, which may include some *overlap and hierarchization among modules*, according to the reaches and hierarchies of relevant functions (or "goods"). The issue applies to many current trends and discussions, such as firm clusters and networks, the idea of "shrinking" and "balkanizing" the internet into smaller, more committed communities, peer-to-peer money and credit systems, small shared economies, and others. Also, maintaining the system's *resilience* requires such modularization into cognitively appropriate arena sizes and maintaining their diversity (e.g., Biggs, Schlueter and Schoon 2015). A simple system, as is obvious, is certainly not a vanishing point of proper complexity reduction.

The issue stretches not simply along the dimension of complexity reduction or increase as such, but rather along the dimension of volatility and crisis vulnerability. It is about proper selective connectivity and (de-)linkage. Current regressive *political reactions* and votes of people against a "globalization" gone astray and against ever more skewed distributions of income, wealth, power and centralities, seem to reflect such *structural aberrations* of CAS that have become *dysfunctional*. Note that, given CAS's often discontinuous behaviors, reducing the system's (over-)complexity and (over-)volatility may be successful in different phases of the system. CAS may be more or less robust or sensitive vis-à-vis policy measures at different times. If the system is in a "basin of attraction," even an inferior one, policy interventions may have to be massive and enduring to have a tangible effect. In other particular phases and areas of the system space, Thaler's famous "nudging" may serve the purpose.

With respect to reducing the *complexity of the decision situation of individual agents*, emerged collectivities (emerged networks or platforms) of instrumentally interacting agents would reflect emerged instrumental social rules and institutions — and, with them, some proper complexity reduction (e.g., Bloch and Metcalfe 2011, 85f.). Policy support for instrumental institutional emergence then will help reduce perceived (over-)complexity and turbulence of agents' decision situations by reconciling complexity levels with agents' *cognitive and emotional/psychic capacities*. It is well-known that, under enforced high environmental *volatility*, the reaction of agents may be switching to higher *rigidity*, as agents can no longer properly organize search and learning, so the entire system will likely slow down in the longer run (e.g., Vega-Redondo 2013). Obviously, some *Polanyian protective countermovement* is at work here against the dismantling of individual decision-making through the gigantism, "globalization," and anonymization by the most powerful, under neoliberal deregulative conditions. This may also explain many current petrifactions (including institutional lock-ins and ceremonial degenerations of institutions) in response to overly extensive deregulation and "globalized flexibility."[22] In this way, qualified

[22] Elsewhere, I have argued that in a model of very large anonymous and/or highly mobile/turbulent populations with frequent random-partner changes, agents would tend to stick to a PD-SG with the same partner as long as possible, or to "meet again" more often, as far as such preferential mixing is feasible for them (Elsner 2005; Elsner and Heinrich 2009).

complexity and size reductions would help reduce short-termism and support a culture of farsightedness and willingness to behaviorally *innovate* (from the overwhelming recent evidence for such a new view on innovation, e.g., Boudreau, Lacetera and Lakhani 2008; Godin and Vinck 2017; Kingston 2017; Komlos 2014; Langley and Tulloch 2017; Sautua 2017; Schrepel 2017; Swann 2014). Policy then, through complexity reduction of individual decision-making, may de-block, accelerate, and stabilize processes of emergence of new rules and institutions, and thus enable and empower agents.

"Non-Algorithmic" Policy Measures

While analytical intractability and some unpredictability of CAS processes quickly come into existence with increasing complexity (reflected in a model building from simple components to a full-fledged evolutionary model, as indicated), *computation* and *simulation* requirements are much higher for CAS and related complexity policy than for simple systems and related policy (including dynamic and stochastic, but still simple systems like DSGEs) (e.g., Desouza and Lin 2011). However, although complex formal methods will be more effective (deploying dynamical-system analyses, SNA, and ABM simulations), forecasting "to the point" and related technocratic hopes of easy and quick "manageability" (point interventions for aspired to-the-point outcomes) will be infeasible. Policy interventions, in this sense, may remain "nonalgorithmic" in some critical instances (e.g., Velupillai 2005, 2007), such as, at tipping points. Policy recommendations will be more "inductive" and experience-based, and required continuous policy adaptations ultimately suggest a "change in the worldview that is currently dominant in policy circles" (Velupillai 2007, 275). Sometimes, one can only say that a massive (institutional) change is required to push the system out of an inferior attractor, but one will not be able to exactly forecast the system's reaction (considering policy evasion or secondary structural impacts, as mentioned). Yet, such computability difficulties do not absolve politics from adopting and maintaining a strong proactive role (Velupillai 2007; see also Durlauf 2012, 62ff.). Drafting "complexity policy," in this sense, would justify Colander and Kupers's (2014) dictum of a complexity-based "art of public policy."

Further "Complexity Hints for Economic Policy": Controlling Tail Risks and Others

Massimo Salzano and David Colander (2007) edited a pioneering book on policy implications of economic complexity even before 2008. In their volume, Mauro Gallegati, Alan Kirman, and Antonio Palestrini (2007), for instance, focus on *power-law distributions of firm sizes* and argue that system stabilization under such structures has to control the "idiosyncratic volatility" caused by certain events at the largest firms (the "tail risks"). They argue for reducing high firm centralities and concentration, particularly by reducing certain legal protections of size and power (namely, their "intellectual property rights") — which immediately appears to be a well-known and common policy reform orientation in a pragmatist policy tradition. But many other policy orientations in the existing literature remain quite general and not directly derived from models, or focused on coherent complexes of measures and tools. Thus, there is still room for further contributions, particularly for a closer look at a specific set of CAS, when striving to advance some more specific and coherent policy orientations — if only exemplarily. While these orientations still may verifiably be related to some model basis and open up further (often surprising) policy perspectives.

A Simple Example of a Frame-Setting Policy for Institutional Emergence

The Simple Approach to the "Evolution of Cooperation"

I refer to Robert Axelrod's ([1984] 2006) well-known approach to the evolution-of-cooperation in PD-SGs, a simple formal reflection of his early complex multi-strategy simulations. It has triggered a surge in the use of PD-SGs and simulations ever since (e.g., Kendall, Yao and Chong 2007; Zeng, Li and Feng 2017).[23] And it holds some exemplary policy relevance. But only a careful evolutionary-institutional interpretation that considers network structures and games on graphs will render a solid basis for sets of policy implications.

The well-known starting point is the prisoners' dilemma (PD) normal form:

$$\begin{matrix} a, a & d, b \\ b, d & c, c \end{matrix}$$

$$\text{with } b > a > c > d \text{ and } a > (d + b)/2.$$

The approach to the superiority of cooperation, in the sense of an evolutionary stability (ES), in a population with randomly matched agents, who are playing many 2x2 PD-SGs, applies one of the usual ES-conditions of EGT. This condition compares defectors' (ALL-D) yields against tit-for-tat-cooperators (TFT) with what cooperators attain playing against their kind.[24] The approach of a SG is the current capital values of related payoff streams compared:

[23] Too often, however, the PD has just been taken for granted. I have elaborated on the ubiquity and everyday relevance of social-dilemma structures elsewhere (e.g., Elsner and Heinrich 2009). Recently, Valentinov and Chatalova (2016) have developed a systems-theoretic explanation of the ubiquity of the PD: Social systems inevitably more or less are operationally closed to their environment, but, at the same time, they are metabolically dependent on it. PDs then originate from the conflict between these two systems' different identities, when systems disregard their environmental dependence. Economic incentives are individual-level projections of systemic imperatives from their artificial closure, and social dilemmas then can be explained in terms of excessive myopic economic incentives, which make individual agents insensitive to their dependence on their environment. Earlier system-theoretic efforts of the institutionalist K. William Kapp (1961) come to mind (see, Berger and Elsner 2007). Myopia plays an important role in analyzing real-world socio-economic CAS throughout this article as well.

[24] TFT, as it is known, starts cooperating and then does what the other agent did in the last interaction. It is the simplest cooperative strategy in a PD-SG that does reflect the sequence of interactions (with one period memory), thus it is responsive and not always strictly dominated (as ALL-C would be).

$$P_{TFT/TFT} = a + \delta a + \delta^2 a + \ldots = \frac{a}{1-\delta};$$

$$P_{ALL\text{-}D/TFT} = b + \delta c + \delta^2 c + \ldots = \frac{c}{1-\delta} + b - c.$$

The ES criterion used here is whether an existing population of cooperators can (or cannot) be invaded by defectors and thus be an ES strategy (or not). In order not to be invaded, incumbents must fare better with each other than invaders against incumbents:

$$P_{TFT/TFT} >!\ P_{ALL\text{-}D/TFT},$$
$$\text{thus } a / (1-\delta) >!\ c / (1-\delta) + b - c$$
$$\delta >!\ (b-a) / (b-c).$$

The result is a logical condition for the institution of cooperation among a population, which is to be embedded in an interpreting narrative.[25] Note that in a simple static EGT approach for PDs, TFT cooperation would not be evolutionarily stable (thus, could be invaded, and could not invade itself, as $b>a$), but the critical condition above depends on the combination of EGT with SGs. That is, it depends on *recurrence* and culturally acquired *time horizons*, which makes the difference (formally, a maximization calculation reflected in the current-capital value of an infinite geometric series of payoffs, the so-called *single-shot solution*).

First, such cooperation is infeasible under one-shot hyper-rationality and myopia and thus under an ES criterion in regular EGT, as noted. However, it may attain an ES status in SGs with emergent proper cognitive conditions and expectations, indicated by the *discount factor* δ, which is equivalent to the expectation of meeting the same agent again in the next interaction, i.e., a criticality of recurrence. In a population, it is also equivalent to meeting any "knowing" third agent, who may be informed about an agent's earlier behavior (through monitoring, memory or a reputation chain), or even to the experienced general expectation (a general *trust*) of meeting a cooperator in the next interaction. In a sequential interaction process, this would require social learning and cultural acquisition of a related longer-term perspective (a higher δ). A question for a more complex modeling then is the actual

[25] The related question, when a population of defectors is invaded by TFT cooperators is: What would the minimum critical mass (or minimum critical share) of TFT cooperators be that can invade, survive, and expand in a defector population and take it over (e.g., Elsner and Heinrich 2009)? This is the case since, according to the ES criterion as used here, TFT obviously would never be an ES strategy against ALL-D.

emergence — or cultural acquisition — of such longer-term rationality. Again, the longer time horizon is indicated by a higher δ — i.e., a high (perceived) probability — in any particular interaction that the interaction will continue with (i.e., meeting again) the same interaction partner (or a "knowing" third or a generally cooperative one, as said).

Second, *habituation* of cooperation as a social institution may (and must) emerge, as agents must "irrationally" sacrifice their short-term maximum *b*, then receiving *a* (their sacrifice then would be *b–a*). A social institution, solving a PD-SG through established habituated cooperation, therefore, must be a social rule plus an endogenous-sanction mechanism that must be exerted through the credible threat of a trigger strategy, such as TFT, to defect upon defection and to punish the defector, even at a cost for oneself (such as possibly *c–a*). This then may prevent agents from chasing after their myopic maximum, which is achievable only through free-riding and exploiting others (but not achievable among equally clever agents, who then run into the dilemma — the static Nash equilibrium). As the institution of cooperation cannot be attained by "hyper-rational" myopic maximization (even if repeated, they would play series of one shots only), it must become habituated and pursued semi-consciously by "rational fools" (Sen 1977). In other words, it must be pursued as an institution, so long as there is no reason to expect that in the next interaction the partner will intend to exploit.

The single-shot payoffs, should the PD be solved, will transform the PD into a less intricate coordination game (with now two Pareto-different Nash equilibria, including the cooperative one),[26] which makes the superior solution more feasible. Note that, in the evolution-of-cooperation tradition, a large number of elaborated models and approaches have emerged that analyze more conditions of evolving cooperation. One of these conditions shows that, with an infinite number of strategies that can be developed and learned by agents, ever more sophisticated and more or less cooperative strategies may emerge and will — more or less — continue to dominate (e.g., Lindgren 1997 and follow-up simulations). A second condition holds that proper small-world topologies will, overall, be advantageous to institutional emergence (e.g., Watts 1999). This all bears relevant policy implications, and I will address some more of them and related critical factors below.

Some Immediate Policy Implications

A general policy perspective for the solution of a social *coordination problem* with Pareto-different Nash equilibria, in particular a stag-hunt structure, which will not be solved under general distrust, was already presented by Amartya Sen (1967). In a context of an endogenous national development strategy and a related collective saving effort of a population to build a national capital and investment stock, he introduced the idea of a public assurance that all agents will contribute to the national capital fund, forego current consumption, and increase saving so as to build

[26] Thus, a stag-hunt. On my use of the Pareto criterion, see Footnote 18.

that national stock in order to benefit the next generation (and not only the agents' own offspring). This coordination problem thus was termed "assurance" game. A credible public assurance would be equivalent to an informal *contrât social* (as introduced by Jean-Jacques Rousseau, who also introduced the example of a stag hunt in 1762), creating a *focal point*, related to a *general-trust* building, to which all will contribute in order to commonly yield the Pareto-superior coordination solution.

Solving *social dilemma* problems with the help of policy, however, is not always that clear. In any sequential interaction, the dilemma structure still continues to exist with its dominating incentive to defect. As long as agents remain uncertain, hyper-rational and myopic, thus playing a series of one-shots, the resulting process will not be problem-solving. A superior, instrumental solution may remain completely blocked, and the system will be caught in the one-shot Nash logic. Moreover, the emergence of an instrumental institutional solution might prove to be very time-consuming. An actually emerged instrumental institution, finally, may be endogenously fragile and prone to backslides or a complete collapse, depending on the particular parameter settings and paths of the evolutionary process. Thus, there are more requirements, reasons, and space for policy support of improved self-organization mechanisms and a related faster and more stable instrumental institutional emergence.

As Axelrod ([1984] 2006) first demonstrated, some specific policy support is warranted, even on the basis of such a simple analytic exercise. Axelrod pointed to two complexes of policy measures:

1. According to the "single-shot" inequality above, there has to be a gradual improvement of the quantitative incentive (payoff) structure in favor of cooperation through rewarding common cooperation (a↑), punishing defection (b↓, c↓), reducing the costs of common cooperation (b–a)↓,[27] increasing the frustration (b–c)↑, and — overall — *weakening the social dilemma*. This would make the structure less intricate and difficult to be solved in an evolutionary-population process, without necessarily dissolving the PD structure as such. Formally, it is about reducing the right-hand side of the inequality above, so that the probability of its realization and of the emergence of a superior, instrumental solution in an evolutionary process increases.[28]
2. The recognition of interdependence (*recognized interdependence* is another older institutionalist issue; see Bush 1999) has to be promoted — particularly, the awareness of a common future, enlarging the time horizon in a social learning process ("enlarging the shadow of the future," see Axelrod [1984] 2006). Technically speaking, this renders the inequality above more likely to hold from

[27] Note, however, that costs of common cooperation hardly exist among equally "clever," hyper-rational, individualist agents, who will get (c, c) anyway. Thus, among those, costs are usually (c–a), as said, which in fact would indicate the potential gain for all.

[28] We have elaborated on this policy implication more formally elsewhere (Elsner, Heinrich and Schwardt 2015, 514ff).

its left-hand side. The emergence of a culturally acquired, longer-term perspective (a longer-term calculation, as indicated), in the form of an enlightened self-interest, would support reciprocity. This whole complex is also an older institutionalist recognition, with which John R. Commons ([1934] 1990) extensively dealt with as *futurity* (for a recent institutionalist "horizonal approach," see Jennings 2005).

Axelrod already provided *policy examples* regarding the second complex of measures, such as involving agents in series of common projects that overlap over time, so that agents always have the opportunity, and realistic expectation, to "meet again" (formally, increasing the value of δ). In previous works, I (Elsner 2001, 2005) have elaborated on both complexes and provided a real-world case study, confirming that *local/regional networking* on identifiable collective issues through overlapping projects, as well as forms of Sen's *public assurance* (that all relevant agents will contribute) may serve to reinforce the second complex. I have also demonstrated how the first complex may be addressed through non-pecuniary payoff components added by the public agent, such as a selective early provision of exclusive critical information control of the policy agent to cooperating agents. On the other hand, providing just pecuniary subsidies to generate a sufficient level of cooperation in sufficiently short time periods might be fiscally too costly.

Generally speaking, this together can be considered a cheaper and leaner policy, particularly as compared to a full public production of the public good ("on behalf" of the "failing market"), or a full subsidization of cooperative behavior to make cooperation the individualistically dominant behavior (similarly, e.g., Colander and Kupers 2014; McCain 2009, 85ff.). In addition, completely eliminating the dilemma structure as such through subsidies would not only be rather costly for the public agent, but would also constitute a "static" solution (hence theoretically trivial as well), rather than a solution that has been *learned* and *habituated* by the private agents in a process. Private agents need to be held liable rather for their individual interests in the collective solution (as indicated by the payoffs *a*), and should correspondingly *contribute* through appropriate behavior. And the agents' voluntary contribution should be intrinsically learned and informally emerge in an adaptive process among themselves, rather than being imposed on them (or provided in lieu of them) by the public agent. In fact, any gradual improvement of critical conditions will increase the probability of attaining a social solution in the evolutionary process.

The policy agent, in turn, needs to care that emergent private solutions will indeed be consistent with broader public concerns. That is, by supporting the win-win situation for the agents involved, agents would help provide a collective good with a *public good* dimension, rather than just colluding at the expense of third parties (like in a cartel). As I have indicated, the simple single-shot solution may be elaborated for a *maximal population size* or minimum cooperators' share, providing *cognitive conditions* with proper expectations "to meet (again)." Arena, platform, and carrier-group sizes, thus, turn out to be another critical factor for structural emergence, and hence for policies. I will take this up again in more detail.

More Policy Implications from the Economic "Deep Structure": Interactions on Networks in an Evolutionary-Institutional Perspective

A New "Framework" Approach

The examples above reflect a more general principle of an institutionally informed "complexity policy." While the "market," as a complex system in the real world, is subject to system(at)ic failure and self-degeneration, if not properly regulated, the public agent may implement conditions for longer-term individual and collective rationality into such a decentralized spontaneous system. Such publicly implemented conditions would then bring about a better collective-action capacity and provide some control over private interaction systems in order to mitigate systemic failure and improve the system's path. However, there is no reason to assume that the public agent, even a sophisticated, well-informed, well-advised, and well-qualified one, would "know everything" or would always "know better." Rather, the complex behavior of CAS suggests that the policy agent systematically makes use of the knowledge and adaptations of private agents in order to control, steer, improve, and stabilize the system. This implies some policy vision that one may qualify as a *specific new kind of frame-setting* policy, which allow the interaction systems of the private agents to go through their adaptations.[29]

Such a specified framework approach — based on an interactive relationship between these different systems and levels of knowledge, decisions, and actions (private-individual-interactive-local, public-systemic-structural-global) — has (somewhat misleadingly) been called "activist *laissez-faire* policy" by Colander and Kupers (2014, 214ff.) or "political stewardship" by others (e.g., Beinhocker 2012; Hallsworth 2012; as well as Colander and Kupers 2014, 240ff.). It seems more appropriate to speak of a "norm influencing role for government … designed to influence the rules … of the social game," in which case the government may indeed become "a means through which individuals solve collective problems" (Colander and Kupers 2014, 186).

Basic Policy Orientations Inferable So Far

Policy orientations inferable so far include identifying mechanisms and critical factors that generate the visible and measurable complex processes and system motions, and the complexes of policy tools and measures addressing them. In more detail, basic starting points and orientations, substantial and procedural ones, are:

- The awareness, on the part of agents, of a recurrent (and often intricate) interdependence among them: fostering *recognized interdependence*;

[29] This seems to resemble simple mainstream or "ordoliberal" perspectives at first sight. However, it has little to do with pushing the "market" into a one-size-fits-all legal framework and then just let it go. As I further illustrate below, the complexity policy approach not only has to envisage much more intricate dynamics, but it will also have to control the economic CAS through a number of factors that influence its "deep structure" (interaction problems, topology) and mechanisms.

- The *incentive structures*, their kind and quantitative strength (type and degree of "intricacy" of games): gradually improving them from "fierce" to "less fierce" and from "intricate" to "less intricate," allowing agents to adapt accordingly;
- *Futurity*: supporting private agents' cultural acquisition of longer time horizons;
- *Interaction arenas*: designing their sizes and initial network structures, supporting endogenously emerging platforms of cooperation (i.e., emerging networks/ platforms with their carrier groups of institutions);
- *Collective goods*, including natural and social commons, to be "produced" (or reproduced) in those arenas (and emerging platforms) by way of institutionalized cooperation: defining them and identifying their reaches, overlaps, and layered structure;
- Identifying the *deficiencies of the spontaneous, decentralized, private, social provision processes* of collective goods and commons in terms of potential complete blockage, excessive time requirement of emergence, or great fragility (danger of backslides);
- *Public social and political objectives*: identifying the public-interest dimension in those collective goods, to be clarified in a proper legitimate public process;
- *Private interests in those solutions* ("goods"): identifying the payoffs that private agents may get from cooperation in order for the public agent to call on the private agents to contribute accordingly.

More Detailed Policy Orientations, Tools, and Measures, Considering Interactions on Networks

By elaborating on these components, particularly in a "games on networks" perspective, further orientations may be derived.[30] Again, I will not go into policy cases here, but will provide an integration of some so far disparate literature conclusions. There are numerous obvious and tacit overlaps among the following orientations, indicating that effective favorable results can be expected only from systemic constellations and systemic interventions. These orientations, as backed by recent empirical, theoretical, modeling, computational, and experimental research, include:

Improving incentive structures, assuring, and supporting social focal points: In reference to the arguments above, both public assurance in stag-hunt structures and making dilemma-prone incentive structures less fierce and less intricate, may help agents to converge on superior coordination options. For instance, applying the single -shot solution would make it obvious that in *financial-sector* PDs, the short-term payoffs

[30] As I have not dealt with evolutionary macro-models with their aggregate components, I avoid delving into macro-policies here. But this is another area of applied CE and complexity-policy following the great financial crisis. Two recent macro-applications in a broad evolutionary-institutional perspective are by Marisa Faggini and Anna Parziale (2016) (an application of the Kauffman model to coevolutionary federal state structures) and by Nadia Garbellini (2016) (an applied fiscal multiplier analysis demonstrating the value of complexity reductions in fiscal policy against neoliberally generated over-complexity).

from one-sided defection are usually so large in relation to potential cooperative payoffs that an evolutionary, learned, cooperative solution (according to the single-shot logic) in the public interest cannot possibly be expected. The public agent thus would have no choice but to drastically reduce the leverages attainable through financial speculation, individualistic hyper-rationality and one-sided exploitation efforts (greed, fraud) in order to stabilize the system. In solved and transformed PD-SGs (i.e., emerging coordination/stag-hunt structures), public activities, including assurance, may work to generate *Schellingian "focal points"* for some superior coordination (e.g., Arthur 1989; Calvert 1995; McCain 2009).

Network structure I — caring for appropriate arena sizes and network structures to facilitate local clustering and global diffusion of knowledge: Again in reference to the above, both arena sizes and network structures need to be developed as issues for the public policy agent, with a focus on local clusters, selective long-range interconnections, and resulting macro-properties of the entire network of a population (e.g., Kirman 1997). Small-world structures need to be optimized in order to reduce the largest tail risks in highly right-skewed distributions, and central positions need to be controlled and perhaps regularly exchanged among agents. As Paul Ormerod (2012, 37) puts it, "[t]he more knowledge we have of how people are connected on the relevant network … the more chance a policy has of succeeding." For instance, supporting small-world properties, while avoiding too much centrality and power for only a few agents, may render fat-tail distributions more even and less volatile (their graphs getting steeper). In other words, when regulating connectivity structures — in particular, reducing centrality degrees — the small-world property may not be suspended. Rather, a balance of meso-sized clustering and far-reaching global interconnections is to be supported, where, however, the most central positions might be publically controlled (rather than bailed out in repeating crises). Reducing high-level power positions should help stabilizing the systems and increasing their resilience (e.g., Acemoglu et al. 2012, 2015; Biggs, Schlueter and Schoon 2015; Gallegati, Kirman and Palestrini 2007).

Network structure II — shaping the system of interaction arenas: Supporting the cognitive and expectational conditions of emergent cooperation (incentive structures, futurity, information, experience and learning conditions, etc.), require that interaction arenas and cooperation platforms of proper *sizes*, as well as *overlaps* and hierarchy *levels* be considered because they fundamentally shape the cognitive and expectational conditions. Such structures will have to mirror both the overlapping and hierarchical/layered reaches of the basic collective goods or functions. This implies supporting the production of local, regional, national, and global collective goods through "structural" (industrial, regional, environmental, developmental, etc.) policies. Generating proper meso-arenas would help to better meet cognitive capacities — hence increase private problem-solving capacities (e.g., Charness and Yang 2014; Loasby 2012) — because promoting decomposability and shaping interaction density and probabilities "to meet (again)" may help to reduce the complexity of individual decision situations, and thus facilitate the institutionalization of cooperation. Numerous analytical, empirical, simulation, or lab approaches have shown that smaller groups (arenas, platforms) within larger topologies (whole populations) promote the recognized interdependence and futurity, and hence the quality of private decision-making (e.g., Elsner and Schwardt 2014; Kao and Couzin 2014; Marco and Goetz 2017; Mirowski 2013; Vega-Redondo 2013; Richards 2012). This particularly applies when agents also can make voluntary location and partner choices (e.g., Berninghaus, Gueth and Schosser 2013).[31]

Reducing volatility and turbulence by reducing disembedding migration: Reducing the perceived over-complexity and over-turbulence is related to providing proper *timeframes* and some *deceleration* that are required to learn, adapt, habituate, and stabilize expectations and interrelations (e.g., Acemoglu, Ozdaglar and Tahbaz-Salehi 2015; Houser et al. 2014). One particular implication — most obviously, running counter established neoliberal convictions, but making much sense within an evolutionary-institutional interaction perspective — is that the building of such social capital (and institutions) may require reducing current levels of (enforced disembedding or uprooting) migration, while any "mobility"/migration was so crucial as productivity-enhancing in the neoliberal narratives, but which in fact often just reflects, but also causes and contributes to the perceived over-turbulence and related high social costs (e.g., Glaeser, Laibson and Sacerdote 2002; Room 2011; Solari and Gambarotto 2014).

Strengthening agents' capabilities: Strengthening agents' capacities to deal with intricate problem structures requires to provide them with improved information about their interdependence structures (the game type) and interaction histories ("memory") (e.g., Houser et al. 2014). Providing a sufficient time and opportunity for social learning also should support agents' capacities to memorize, monitor, build reputation, use reputation chains, and select partners through such information. It may also be critical to strengthen agents' capacity and willingness to take risks, or face some uncertainty (of being exploited at least once), when trying to escape social dilemmas (a specific capacity, different from an unqualified neoliberal "risk society"). Also, should they be exploited once or twice, behavioral innovators and contributors to the common good should be publicly supported through a climate of non-enviousness, as they can never make up for initial exploitation, even if cooperation begins thereafter. Furthermore, agents need to be encouraged to search and experiment (behaviorally *innovate*) in order to generate the *minimum critical mass* of cooperative behavior required to improve cooperation and to spread it (e.g., Vega-Redondo 2013). A climate of appropriate (threat of) punishment of free-riders and defectors in private interactions systems is usually considered to be supportive of instrumental problem-solving (e.g., Marco and Goetz 2017).

Informational openness and multiple-path creation: Connected to such information endowments and transparency, institutions function as informational

[31] As many of those policy orientations, this appears dubious to police immediately. In another work (Dai and Elsner 2015), we have elaborated on some more operational considerations of shaping arena/network sizes for the case of rural-to-urban migrant workers in China. China, more generally, is a case for some of those orientations addressed above, such as, e.g., cutting back the most severe tail risks of income and wealth and officially targeting a lower national Gini coefficient recently.

and expectational devices. But due to their very habitual character, the originally instrumental institutions may degrade into abstract norms and ceremonial structures, thereby losing their problem-solving capacity when the original problem changes. For instance, when cooperation gains are unevenly distributed, a new social dilemma may emerge with the same institutionalized, but now "petrified" behavior. A proper institutional renewal, however, may be less rewarding initially than the existing old institution, and it may be beneficial only in the longer run (e.g., Elsner 2012; Heinrich and Schwardt 2013). Restoring agents' problem-solving capacities and promoting progressive institutional change, therefore, will require a *breakout* from an institutional lock-in. This may also require some particular information openness. A *multi-standard* policy that breaks up behavioral (in the same way as technological) standards would have to be developed. However, this may not always be feasible under cumulative network externalities, and may even be counterproductive so long as the established standard performs relatively well and still has some problem-solving capacity. So, certain critical conditions must be met for openness policies to become feasible and for new institutional solutions to be learned, and they may only exist in critical time windows (e.g., Heinrich 2013; Houser et al. 2014).

Favoring equality: Formal interaction models have widely established that favoring equality among agents is a warranted general policy orientation (e.g., Binmore 2011, 165ff; Goerner 2017; Hargreaves-Heap 1989; Kirman 2016, 563f). Asymmetric payoffs, by contrast, usually increase intricacy and volatility through continuing wealth-redistribution battles, diverting agents' resources from problem-solving and common or collective wealth creation. It appears from both analytical and experimental analyses that structures with more even payoffs are easier to solve for agents, hence more stable in the longer run and more supportive of voluntary collective-good contributions as well as institutionalized cooperation (e.g., Kesternich, Lange and Sturm 2014; Krockow, Pulford and Colman 2015; Lopez-Perez, Pinter and Kiss 2015; Nishi et al. 2015). In this way, more even payoff structures also increase macroeconomic performance and perceived welfare (e.g., Acemoglu, Ozdaglar and Tahbaz-Salehi 2015).

"New Meritorics," Institutional Policy, and Pragmatism

The specific framework approach, as I have laid it out above, is about shaping factor constellations for CAS (incentive structures, network structures, futurity, mobility conditions, cognitive conditions in a wider sense, etc.) that entail adaptive processes among interacting private agents, a resulting dynamics, and emerging structures with longer-run superior outcomes, which are consistent with broad socio-political goals. This also provides a clearer definition of the relative private and public interests, as well as a more appropriate and effective assignment of the relative private and public responsibilities and contributions, as compared, for instance, to the conventional collective-good theory, where the public agent has to take over completely in the case of an identified "market failure." In the current policy practice, the latter often leads to bailouts of the big system-relevant "tail risks," to opaque "private-public-partnerships," and to thriving but obscure interventionism.

In this more specific framework conception, on the contrary, the policy agent needs to *evaluate the outcomes* of spontaneous private-interaction processes and the resulting complex system dynamics. What are the relevant collective goods, what is the public interest therein, and what are their target levels? What are the current deficiencies of the system processes generating them, what do these deficiencies and the outcomes tell us about defective self-organization mechanisms, inappropriate incentive, institutional, and network structures, insufficient futurity, overstressing mobility, etc.? Important criteria of public regulation will be the probabilities of a complete blockage of aspired structural emergence, the time required for such structural emergence, and the degree of its fragility and potential backslide. Policy orientations then are to unlock (de-block), accelerate, and stabilize processes of instrumental structural emergence. The traditional *merit-good* criteria of "wrong" price and quantity (Musgrave and Musgrave 1973) will have to be extended in view of CAS by the above criteria. It is in this sense that one may speak of a *new meritorics* (e.g., Elsner 2001; ver Eecke 2008).

This, in turn, requires a *strong* state that is capable of determining the public goods, objectives, and target levels, of evaluating the private system outcomes, and of shaping the critical factors of the adaptive processes in a permanent learning and adaptation attitude. Such a state must also always be prepared to quickly and massively intervene in structural and institutional terms, in both supportive and restrictive directions. As the shaping of critical factors of interaction processes and systemic mechanisms is targeted toward institutional structures and structural distributions, one may call it *institutional policy*. As such, it is "doubly interactive" in the sense that it (i) permanently interacts with the entire target CAS and (ii) targets the specific interaction systems and self-organizing mechanisms of the privates.

It is not surprising that such policy implications of economic complexity and CE bring to the fore the relevance of a multifaceted *socio-political evaluation* of complex-system dynamics and its results, which never can be completely known or anticipated. And again, this resembles a conception of policy that was already developed in the 1920s by American *pragmatism* and *instrumentalism* (e.g., Dewey 1925). It was further developed theoretically and implemented practically (at state level and in the frame of the federal-level New Deal) by *institutionalists* in the 1920s and 1930s as a *negotiated economy* (e.g., Commons [1934] 1990) that needs to be accompanied, qualified, and developed by a permanent process of social inquiry and evaluation of (macro and structural, distributional) outcomes — as exactly is the case with CAS and complexity policy. In a negotiated economy, economic values and their relations do not emerge from vacuum, nor are they a "natural" result of a "value-free," "market" mechanism (in fact, they are the obscure results of an economic CAS gone awry). Rather, they need to be bargained and agreed societally (and mainly distributionally), transparent, reasonable, and capable of a broad societal problem-solving (e.g., Ramstad 1991). This was later operationalized by institutionalists into the *instrumental value principle* (e.g., Tool [1979] 2001; for a recent application of a new meritoric policy procedure to the current issues of private power and public control of both the financial sector and internet service provider oligopolies, see Rahman 2017).

By highlighting the many structures, mechanisms, and endless dynamics of real-world CAS, CE today reinforces the older pragmatist approach of an improved problem-solving based on permanent inquiry, learning, experimentation, adaptation, and participation.[32] Complexity economics, in fact, provides massive new causal knowledge for a new broad societal problem-solving and the critical factors and orientations for a qualitatively new policy intervention. Moreover, it makes it obvious that social evaluations are inevitable and required for true progressive institutional reform, with a clear view that CAS dynamics — hence learning and experimentation in policies — will never end.

Conclusion

In the present article, I reviewed the economic complexity literature and existing knowledge about economic CAS, its structures, dynamics, and emergent outcomes. I attempted to show that CE is basically heterodox and hard to reconcile with a simplistic economic mainstream. I also elaborated the consistency, similarities, and overlaps between CE and long-standing questions, issues, and theories of heterodoxies — namely, evolutionary institutionalism. The two originated in completely different contexts and histories, and, at first sight, still seem to represent distinct systems of thought. Thus, I strove to determine the space for convergence and learning from each other between the two paradigmatic systems. On one hand, evolutionary institutionalism can learn from CE about structures, dynamics, and advanced analyses and methods. On the other, CE could profit from the rich history of thought, theory, and experience of evolutionary institutionalism, its deep understanding of epistemology, and strong policy reform orientation. By ignoring these rich traditions, CE runs the risk of reinventing the wheel, and by ignoring CE, original institutional economics could lose the cutting edge.

The proof of the pudding is always in policy. While the literature on policy implications of CE and CAS has surged after the financial crisis of 2008, it still has been — with some exceptions — largely general. So, there still seemed to be room for a specific model-based approach to complexity policy: namely, in a perspective on interactions, networks, long-run collective rationality, mobility, cognitive conditions etc., and particularly in an evolutionary-institutional perspective. With this article, I hope to have contributed to this. So I strove to develop a set of specific, model-based orientations and complexes of tools and measures for a complex institutional policy. I placed this in a perspective of the "evolution-of-cooperation," considering repeated games in populations and on network topologies. I reviewed self-organization mechanisms, resulting dynamics and emergent properties, and corresponding critical factors for policy intervention. I identified a broad set of new orientations, often running counter to the received wisdom of the mainstream, starting from a simple model and showing how its immediate implications can be generalized. The result is a

[32] The institutionalist theory of participatory democracy seems to have encountered a new interest and has been further developed recently (e.g., Scholz-Waeckerle 2016).

socio-political, structural-distributional and institutional conception of policy that is considerably different from, if not running counter to, the still dominant rough-and-ready, "perfect-market"-centered policy.

I outlined an institutional complexity policy as a specified framework approach, a "double-interactive" policy that relates to and works with the private interaction system to foster conditions for superior and problem-solving structural and institutional emergence. Given the dynamics and evolutionary properties of economic CAS, the public agent needs to steer the system among all of the following: emergent institutional structures and often adverse self-organization mechanisms; possible inferior attractors and lock-ins; persistent detrimental distributional structures causing repeated major crises; perceived over-complexity and over-volatility; and breakouts from petrified, ceremonial institutional structure. Technically speaking, the public agent has to influence and steer the system between two dimensions: flexibility vs. volatile randomness, on one hand, and stable order vs. petrified lock-in, on the other. I related the picture of the dynamics of economic CAS to a conception of permanent (and, at times, massive) intervention, concurrent social inquiry, massive computation, forecast, and anticipation, awareness of rapid changes, experimentation, political learning and adaptation, and socio-political evaluation (*new meritorics*), and finally demonstrated its resemblance to the older institutionalist policy conception of pragmatism and instrumentalism. Such policy deeply relates to shaping human cognitive and expectational conditions.

Further implications suggest a higher complexity, strength, power, and qualification of the public control system over the private target system, as well as higher (and different) computational requirements (than in current reality), longer-term public commitment and adaptability, and stronger democratic-participatory legitimation and assessment. With its committed and reliable proactive frame-setting, this approach should also be less expensive than current opaque crisis interventionism and rampant bailouts of the rich and powerful. Such policy will be aware of the target system's path-dependence, non-linearities, cumulative processes, idiosyncrasies, and particular non-predictabilities. Policy recommendations, therefore, are much less apodictic than in the current practice of policy advice, as well as much less susceptible to false predictions. These policy recommendations require the use of alternative modeling, multiple computations, simulating alternative paths, and exploring the spaces of policy discretion. That is, no simple automatisms will do, but only full *awareness of the value decisions* to be taken. Thus, I found (un-)surprising similarities with the pragmatist policy conception of institutionalism. The role of a value-based, socio-political process comes to the fore through CE by the very opening of the huge black box of the mainstream's "market" in both theory and policy.

References

Acemoglu, Daron, Vasco M. Carvalho, Asuman Ozdaglar and Alireza Tahbaz-Salehi. "The Network Origins of Aggregate Fluctuations." *Econometrica* 80, 5 (2012): 1977-2016.

Acemoglu, Daron, Asuman Ozdaglar and Alireza Tahbaz-Salehi. "Networks, Shocks, and Systemic Risk." Columbia Business School Research Paper No. 15-18, 2015. Available at https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2560015. Accessed January 20, 2017.

Aoki, Masahiko, Kenneth Binmore, Simon Deakin and Herbert Gintis, eds. *Complexity and Institutions: Markets, Norms and Corporations*. Basingstoke, UK: Palgrave Macmillan, 2012.

Arthur, Brian. "Competing Technologies, Increasing Returns, and Lock-in by Historical Events." *Economic Journal* 99 (1989): 116-131.

——. "Complexity Economics: A Different Framework for Economic Thought." SFI Working Paper No. 2013-04-012, 2013. Available at http://tuvalu.santafe.edu/~wbarthur/Papers/Comp.Econ.SFI.pdf. Accessed January 20, 2017.

——. *Complexity and the Economy*. Oxford, UK: Oxford University Press, 2015.

Arthur, Brian, Steven Durlauf and David Lane, eds. *The Economy as an Evolving Complex System II*. Reading, MA: Addison-Wesley, 1997.

Ashby, W. Ross. *An Introduction to Cybernetics*. London, UK: Chapman & Hall, 1956.

Aspara, Jaakko, Kalle Pajunen, Henrikki Tikkanen and Risto Tainio. "Explaining Corporate Short-Termism: Self-Reinforcing Processes and Biases Among Investors, the Media and Corporate Managers." *Socio-Economic Review* 12, 4 (2014): 667-693.

Axelrod, Robert. *The Evolution of Cooperation*. New York, NY: Basic Books, [1984] 2006.

Bak, Per, Chao Tang and Kurt Wiesenfeld. "Self-Organized Criticality: An Explanation of 1/*f* Noise." *Physical Review Letters* 59, 4 (1987): 381-384.

Barabási, Albert-László and Réka Albert. "Emergence of Scaling in Random Networks." *Science* 284, 5439 (1999): 509-512.

Battiston, Stefano, Guido Caldarelli, Robert May, Tarik Roukny and Joseph E. Stiglitz. "The Price of Complexity in Financial Networks." SSRN, 2015. Available at http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2594028. Accessed January 20, 2017.

Bednar, Jenna, Andrea Jones-Rooy and Scott E. Page. "Choosing a Future Based on the Past: Institutions, Behavior, and Path-Dependence." *European Journal of Political Economy* 40 (2015): 312-332.

Beinhocker, Eric. *The Origin of Wealth: Evolution, Complexity and the Radical Remaking of Economics*. London, UK: Random House, 2007.

——. "New Economics, Policy and Politics." In *Complex New World: Translating New Economic Thinking into Public Policy*, edited by Tony Dolphin and David Nash, pp. 134-146. London, UK: Institute for Public Policy Research, 2012.

Berger, Sebastian and Wolfram Elsner. "European Contributions to Evolutionary Institutional Economics: The Cases of 'Cumulative Circular Causation' (CCC) and 'Open Systems Approach' (OSA). Some Methodological and Policy Implications." *Journal of Economic Issues* 41, 2 (2007): 529-537.

Berninghaus, Siegfried, Werner Gueth and Stephan Schosser. "Reciprocity in Locating Contributions: Experiments on the Neighborhood Public Good Game." *Games* 4, 2 (2013): 144-162.

Biggs, Reinette, Maja Schlueter and Michael Schoon, eds. *Principles for Building Resilience*. Cambridge, UK: Cambridge University Press, 2015.

Binmore, Ken. *Natural Justice*. Oxford, UK: Oxford University Press, 2011.

Bloch, Harry and Stan Metcalfe. "Complexity in the Theory of the Developing Firm." In *Handbook on the Economic Complexity of Technological Change*, edited by Cristiano Antonelli, pp. 81-104. Cheltenham, UK, Northampton, MA: Elgar, 2011.

Boudreau, Kevin J., Nicola Lacetera and Karim R. Lakhani. "Parallel Search, Incentives and Problem Type: Revisiting the Competition and Innovation Link." Harvard Business School Working Paper 09-041. Harvard Business School, 2008. Available at www.hbs.edu/faculty/Publication%20Files/09-041_145bb20b-48dc-42ef-b230-5f1c523a19e0.pdf. Accessed September 1, 2017.

Bush, Paul. "The Theory of Institutional Change." *Journal of Economic Issues* 21, 3 (1987): 1075-1116.

——. "Recognized Interdependence." In *Encyclopedia of Political Economy*, edited by Philipp O'Hara, vol. 2, pp. 963-964. London, UK: Routledge, 1999.

Calvert, Randall. "The Rational Choice Theory of Institutions: Implications for Design." In *Institutional Design*, edited by David Weimer, pp. 63-94. New York, NY: Springer, 1995

Charness, Gary and Chun-Lei Yang. "Starting Small Towards Voluntary Formation of Efficient Large Groups in Public Goods Provision." *Journal of Economic Behavior and Organization* 102 (2014): 119-132.

Clement, Julien and Phanish Puranam. "Searching for Structure: Formal Organization Design as a Guide to Network Evolution." *Management Science* (2017). Available at https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2974436. Accessed September 3, 2017.

Colander, David, Richard Holt and J. Barkley Rosser. "The Complexity Era in Economics." *Review of Political Economy* 23, 3 (2011): 357-369.
Colander, David and Roland Kupers. *Complexity and the Art of Public Policy: Solving Society's Problems from the Bottom Up*. Princeton, NJ: Princeton University Press, 2014.
Commons, John. *Institutional Economics: Its Place in Political Economy*. New York, NY: Transaction Publishers, [1934] 1990.
Dai, Shuanping and Wolfram Elsner. "Declining Trust in Growing China." Working Paper, 2015. Available at https://ideas.repec.org/p/zbw/udedao/1012015.html. Accessed January 31, 2017.
David, Paul. "Clio and the Economics of QWERTY." *American Economic Review* PP 75, 2 (1985): 332-337.
Davidson, Paul. "Rational Expectations: A Fallacious Foundation for Studying Crucial Decision-Making Processes." *Journal of Post-Keynesian Economics* V, 2 (1982–1983): 182-198.
——. "A Rejoinder to O'Donnell's Critique of the Ergodic/Nonergodic Explanation of Keynes's Concept of Uncertainty." *Journal of Post-Keynesian Economics* 38, 1 (2015): 1-18.
Davis, John. "Complexity Theory's Network Conception of the Individual." In *Money and Markets: A Doctrinal Approach*, edited by Alberto Giacomin and Maria Cristina Marcuzzo, pp. 30-47. London, UK: Routledge, 2007.
——. "Agent-Based Modeling's Open Methodology Approach: Simulation, Reflexivity, and Abduction." SSRN, September 2, 2017. Available at https://ssrn.com/abstract=3031223. Accessed September 7, 2017.
Desouza, Kevin C. and Yuan Lin. "Towards Evidence-Driven Policy Design: Complex Adaptive Systems and Computational Modeling." *Innovation Journal* 16, 1 (2011): 1-19.
Dewey, John. *The Development of American Pragmatism: In Philosophy and Civilization.* New York, NY: Capricorn Books, 1925.
Dolphin, Tony and David Nash, eds. *Complex New World: Translating New Economic Thinking into Public Policy*. London, UK: Institute for Public Policy Research, 2012.
Durlauf, Steven. "What Should Policymakers Know About Economic Complexity?" 1997. Available at https://ideas.repec.org/p/wop/safiwp/97-10-080.html. Accessed January 20, 2017.
——. "Complexity, Economics, and Public Policy." *Politics, Philosophy & Economics* 11, 1 (2012): 45-75.
Elsner, Wolfram. "Interactive Economic Policy: Toward a Cooperative Policy Approach for a Negotiated Economy." *Journal of Economic Issues* 35, 1 (2001): 61-83.
——. "Real-World Economics Today: The New Complexity, Coordination, and Policy." *Review of Social Economy* 63, 1 (2005): 19-53.
——. "The Theory of Institutional Change Revisited: The Institutional Dichotomy, Its Dynamic, and Its Policy Implications in a More Formal Analysis." *Journal of Economic Issues* 46, 1 (2012): 1-43.
——. "State and Future of the 'Citadel' and of the Heterodoxies in Economics: Challenges and Dangers, Convergences and Cooperation." *European Journal of Economics and Economic Policies: Intervention* 10, 3 (2013): 286-298.
——. "Social Economics and Evolutionary Institutionalism Today: Theoretical Components and 'Heterodox' Convergence in a Socio-Economic Perspective." *Forum for Social Economics* 46, 1 (2017): 52-77.
Elsner, Wolfram and Torsten Heinrich. "A Simple Theory of 'Meso': On the Coevolution of Institutions and Platform Size." *Journal of Socio-Economics* 38 (2009): 843-858.
Elsner, Wolfram and Henning Schwardt. "Trust and Arena Size: Expectations, Institutions, General Trust, and Critical Population and Group Sizes." *Journal of Institutional Economics* 10, 1 (2014): 107-134.
Elsner, Wolfram, Torsten Heinrich and Henning Schwardt. *Microeconomics of Complex Economies: Evolutionary, Institutional and Complexity Perspectives*. San Diego, CA: Elsevier, 2015.
Epstein, Joshua and Robert Axtell. *Growing Artificial Societies: Social Science from the Bottom Up*, Cambridge, MA: MIT Press, 1996.
Faggini, Marisa and Anna Parziale. "A New Perspective for Fiscal federalism: The NK Model." *Journal of Economic Issues* 50, 4 (2016): 1069-1104.
Fontana, Magda. "Can Neoclassical Economics Handle Complexity? The Fallacy of the Oil Spot Dynamic." *Journal of Economic Behavior & Organization* 76, 3 (2010): 584-596.
——. "Policy in Complex Social Systems." In *Good Government, Governance, Human Complexity*, edited by P. Heritier and P. Silvestri, pp. 221-233. Firenze, Italy: L.S. Olschki, 2012.

Fontana, Magda and Pietro Terna. "From Agent-Based Models to Network Analysis (and Return): The Policy-Making Perspective." Working Paper No. 07/15. Università Degli Studi di Torino, 2015.

Foster, John. "From Simplistic to Complex Systems in Economics." *Cambridge Journal of Economics* 29, 6 (2005): 873-892.

——. "Why Is Economics Not a Complex Systems Science?" *Journal of Economic Issues* 40, 4 (2006): 1069-1091.

Gallegati, Mauro and Alan Kirman. "Reconstructing Economics: Agent Based Models and Complexity." *Complexity Economics* 1 (2012) 5-31.

Gallegati, Mauro, Alan Kirman and Antonio Palestrini. "Implications of Scaling Laws for Policy-Makers." In *Complexity Hints for Economic Policy*, edited by Massimo Salzano and David Colander, pp. 291-302. New York, NY: Springer, 2007.

Garbellini, Nadia. "Small Fiscal Multipliers Do Not Justify Austerity: A Macroeconomic Accounting Analysis of Public Debt-to-GDP Dynamics." *Journal of Economic Issues* 50, 4 (2016): 1027-1044.

Garnsey, Elizabeth and James McGlade. *Complexity and Co-Evolution: Continuity and Change in Socio-Economic Systems*. Cheltenham, UK: Edward Elgar, 2006.

Geyer, Robert and Paul Cairney, eds. *Handbook on Complexity and Public Policy*. Cheltenham, UK: Edward Elgar, 2015.

Geyer, Robert and Samir Rihani. *Complexity and Public Policy: A New Approach to Twenty-First Century Politics, Policy and Society*. London, UK: Routledge, 2010.

Gilles, Robert, Emiliya Lazarova and Pieter Ruys. "Stability in a Network Economy: The Role of Institutions." *Journal of Economic Behavior and Organization* 119 (2015): 375-399.

Glaeser, Edward, David Laibson and Bruce Sacerdote. "An Economic Approach to Social Capital." *Economic Journal* 112, 483 (2002): F437-F458.

Godin, Benoît and Dominique Vinck, eds. *Critical Studies of Innovation: Alternative Approaches to the Pro-Innovation Bias*." Cheltenham, UK: Edward Elgar, 2017.

Goerner, Sally. "The Science of Flow Says Extreme Inequality Causes Economic Collapse." *Evonomics*, 2017. Available at http://evonomics.com/science-flow-says-extreme-inequality-causes-economic-collapse/. Accessed September 1, 2017.

Hallsworth, Michael. "How Complexity Economics Can Improve Government: Rethinking Policy Actors, Institutions, and Structures." In *Complex New World: Rethinking Policy Actors, Institutions and Structures*, edited by Tony Dolphin and David Nash, pp. 39-49. London, UK: Institute for Public Policy Research, 2012.

Hargreaves-Heap, Shaun. *Rationality in Economics*. New York, NY: Blackwell, 1989.

Harper, David and Paul Lewis. "New Perspectives on Emergence in Economics." *Journal of Economic Behavior and Organization* 82, 2-3 (2012): 329-337.

Hayden, F. Gregory. *Policymaking for a Good Society: The Social Fabric Matrix Approach to Policy Analysis and Program Evaluation*. New York, NY: Springer, 2006.

Heinrich, Torsten. *Technological Change and Network Effects in Growth Regimes: Exploring the Microfoundations of Economic Growth*. London, UK: Routledge, 2013.

Heinrich, Torsten and Henning Schwardt. "Institutional Inertia and Institutional Change in an Expanding Normal-Form Game." *Games* 4 (2013): 398-425.

Helbing, Dirk. "Globally Networked Risks and How to Respond." *Nature* 497 (2013): 51-59.

Hodgson, Geoffrey M. "Reconstitutive Downward Causation: Social Structure and the Development of Individual Agency." In *Intersubjectivity in Economics: Agents and Structures*, edited by Edward Fullbrook, pp. 159-180. London, UK: Routledge, 2002.

Holland, John. "Studying Complex Adaptive Systems." *Journal of Systems Science and Complexity* 19, 1 (2006): 1-8.

Houser, Daniel, David Levy, Kail Padgitt, Sandra Peart and Erte Xiao. "Raising the Price of Talk: An Experimental Analysis of Transparent Leadership." *Journal of Economic Behavior and Organization* 105 (2014): 208-218.

Hu, Hai-Hua, Jun Lin and Wen-tian Cui. "Intervention Strategies and the Diffusion of Collective Behavior." *Journal of Artificial Societies and Social Simulation* 18, 3 (2015): 1-14.

Jackson, Matthew and Yves Zenou. "Games on Networks." In *Handbook of Game Theory*, edited by Peyton Young and Shmuel Zamir, vol. 4, pp. 91-157. Amsterdam, Netherlands: Elsevier, 2015.

Jackson, Matthew, Brian Rogers and Yves Zenou. "The Economic Consequences of Social Network Structure." SSRN, 2015. Available at http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2467812. Accessed January 24, 2017.

Jennings, Frederic. "How Efficiency/Equity Trade-offs Resolve through Horizon Effects." *Journal of Economic Issues* 39, 2 (2005): 365-373.

Jun, Tackseung and Rajiv Sethi. "Neighborhood Structure and the Evolution of Cooperation." *Journal of Evolutionary Economics* 17 (2007): 623-646.

Kao, Albert and Lain Couzin. "Decision Accuracy in Complex Environments Is Often Maximized by Small Group Sizes." Proceedings of the Royal Society B 281, 1784. Royal Society, 2014. Available at http://classic.rspb.royalsocietypublishing.org/content/281/1784/20133305.short. Accessed January 24, 2017.

Kapp, K. William. *Toward a Science of Man in Society: A Positive Approach to the Integration of Social Knowledge*. The Hague, Belgium: Martinus Nijhoff, 1961.

Kauffman, Stuart. *The Origins of Order: Self-Organization and Selection in Evolution*. Oxford, UK: Oxford University Press, 1993

Kendall, Graham, Xin *Yao* and Siang Yew *Chong, eds*. The *Iterated Prisoner's Dilemma: 20 Years On*. Singapore: World Scientific, 2007.

Kesternich, Martin, Andreas Lange and Bodo Sturm. "The Impact of Burden Sharing Rules on the Voluntary Provision of Public Goods." *Journal of Economic Behavior and Organization* 105 (2014): 107-123.

Kingston, William. *How Capitalism Destroyed Itself: Technology Displaced by Financial Innovation*. Aldershot, UK: Edward Elgar, 2017.

Kirman, Alan. "The Economy as an Evolving Network." *Journal of Evolutionary Economics* 7 (1997): 339-353.

——. *Complex Economics: Individual and Collective Rationality*. London, UK: Routledge, 2011.

——. "Complexity and Economic Policy: A Paradigm Shift or a Change in Perspective? A Review Essay on David Colander and Roland Kupers's *Complexity and the Art of Public Policy*." *Journal of Economic Literature* 54, 2 (2016): 534-572.

Komlos, John. "Has Creative Destruction Become More Destructive?" NBER Working Paper No. 20379. Cambridge, MA: NBER, 2014.

Krockow, Eva, Briony Pulford and Andrew Colman. "Competitive Centipede Games: Zero-End Payoffs and Payoff Inequality Deter Reciprocal Cooperation." *Games* 6, 3 (2015): 262-272.

Langley, Greg and James Tulloch. "Capitalism's Creation Myth Revisited." 2017. Available at https://projectm-online.com/risk/capitalisms-creative-destruction/. Accessed September 1, 2017.

Lewin, Peter. "Policy Design and Execution in a Complex World: Can We Learn from the Financial Crisis?" Dallas, TX: University of Texas, 2014. Available at http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2473258. Accessed January 24, 2017.

Lindgren, Kristian. "Evolutionary Dynamics in Game-Theoretic Models." In *The Economy as an Evolving Complex System II*, edited by W. Brian Arthur, Steven Durlauf, and David Lane, pp. 337-367. Reading, MA: Addison-Wesley, 1997.

Lloyd, Seth. "Measures of Complexity: A Nonexhaustive List." *IEEE Control Systems Magazine* (August 2001): 7-8.

Loasby, Brian. "Building Systems." *Journal of Evolutionary Economics* 22, 4 (2012): 833-846.

Lopez-Perez, Raul, Agnes Pinter and Hubert Kiss. "Does Payoff Equity Facilitate Coordination? A Test of Schelling's Conjecture." *Journal of Economic Behavior and Organization* 117 (2015): 209-222.

Lux, Thomas and Michele Marchesi. "Scaling and Criticality in a Stochastic Multi-Agent Model of a Financial Market." *Nature* 397 (1999): 498-500.

Mandelbrot, Benoit. *Fractals and Scaling in Finance: Discontinuity, Concentration, Risk*. Heidelberg, Germany: Springer, 1997.

Mandelbrot, Benoit and Richard L. Hudson. *The Misbehavior of Markets: A Fractal View of Financial Turbulence*. New York, NY: Basic Books, 2006.

Marco, Jorge and Renan-Ulrich Goetz. "Tragedy of the Commons and Evolutionary Games in Social Networks: The Economics of Social Punishment." FEEM Working Paper No. 35. FEEM, 2017. Available at https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2998546. Accessed September 1, 2017.

Markose, Sheri M. "Complex Type 4 Structure Changing Dynamics of Digital Agents: Nash Equilibria of a Game with Arms Race in Innovations." University of Essex, 2016. Available at https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2900533. Accessed February 2, 2017.

McCain, Roger. *Game Theory and Public Policy*. Cheltenham, UK: Edward Elgar, 2009.

Miller, John and Scott Page. *Complex Adaptive Systems: An Introduction to Computational Models of Social Life*. Princeton, NJ: Princeton University Press, 2007.

Mirowski, Philip. "Market Complexity and the Nature of Crises in Financial Markets." In *Social Fairness and Economics: Economic Essays in the Spirit of Duncan Foley*, edited by Lance Taylor, Armon Rezai and Thomas Michl, pp. 374-393. London, UK: Routledge, 2013.

Mitchell, Melanie. *Complexity: A Guide*. Oxford, UK: Oxford University Press, 2009.

Morçöl, Göktu. *A Complexity Theory for Public Policy*. London, UK: Routledge, 2012.

Musgrave, Richard A. and Peggy B. Musgrave. *Public Finance in Theory and Practice*. New York, NY: McGraw-Hill, 1973.

Nishi, Akihiro, Hirokazu Shirado, David Rand and Nicholas Christakis. "Inequality and Visibility of Wealth in Experimental Social Networks." *Nature* 526, 7573 (2015): 426-429.

Nowak, Martin. *Evolutionary Dynamics: Exploring the Equations of Life*. Cambridge, MA: Harvard University Press, 2006.

O'Donnell, Rod. "A Critique of the Ergodic/Nonergodic Approach to Uncertainty." *Journal of Post-Keynesian Economics* 37, 2 (2014): 187-209.

OECD. *Applications of Complexity Science for Public Policy: New Tools for Finding Unanticipated Consequences and Unrealized Opportunities*. Paris, France: OECD, 2009.

——. *Debate the Issues: Complexity and Policy Making*. Edited by Patrick Love and Julia Stockdale-Otárola. Paris, France: OECD, 2017

Ormerod, Paul. "Networks and the Need for a New Approach to Policymaking." In In *Complex New World: Translating New Economic Thinking into Public Policy*, edited by Tony Dolphin and David Nash, pp. 28-38. London, UK: Institute for Public Policy Research, 2012.

Page, Scott. "A Complexity Perspective on Institutional Design." *Politics, Philosophy & Economics* 11, 1 (2012): 5-25.

Peneder, Michael. "Competitiveness and Industrial Policy: From Rationalities of Failure Towards the Ability to Evolve." *Cambridge Journal of Economics* 41 (2017): 829-858.

Price, Jim et al. "The Policymaker's Complexity Toolkit." In *Handbook on Complexity and Public Policy*, edited by Robert Geyer and Paul Cairney, pp. 92-110. Cheltenham, UK: Edward Elgar, 2015.

Prigogine, Ilya and Gregoire Nicolis. "On Symmetry-Breaking Instabilities in Dissipative Systems." *Journal of Chemical Physics* 46 (1967): 3542-3550.

Rahman, K. Sabeel. "Private Power, Public Values: Regulating Social Infrastructure in a Changing Economy." *Cardozo Law Review* 39, 5 (2017). Available at https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2986387. Accessed September 1, 2017.

Ramstad, Yngve. "From Desideratum to Historical Achievement: John R. Commons's Reasonable Value and the 'Negotiated Economy' of Denmark." *Journal of Economic Issues* 25, 2 (1991): 431-439.

Richards, Sue. "Regional Policy and Complexity: Towards Effective Decentralisation." In *Complex New World: Rethinking Policy Actors, Institutions and Structures*, edited by Tony Dolphin and David Nash, pp. 121-133. London, UK: Institute for Public Policy Research, 2012.

Robert, Verónica, Gabriel Yoguel and Octavio Lerena. "The Ontology of Complexity and the Neo-Schumpeterian Evolutionary Theory of Economic Change." *Journal of Evolutionary Economics* 27 (2017): 761-793.

Room, Graham. *Complexity, Institutions and Public Policy. Agile Decision-Making in a Turbulent World*. Cheltenham, UK: Edward Elgar, 2011.

Rosser, J. Barkley. "Reconsidering Ergodicity and Fundamental Uncertainty." *Journal of Post-Keynesian Economics* 38, 3 (2015–2016): 331-354. Available at www.tandfonline.com/doi/abs/10.1080/01603477.2015.1070271. Accessed January 18, 2017.

Salzano, Massimo and David Colander, eds. *Complexity Hints for Economic Policy*. Milan, Italy: Springer, 2007.

Sautua, Santiago. "Does Uncertainty Cause Inertia in Decision Making?" *Journal of Economic Behavior & Organization* 136 (2017): 1-14.

Schelling, Thomas. "Dynamic Models of Segregation." *Journal of Mathematical Sociology* 1 (1971): 143-186.

Scholz-Waeckerle, Manuel. "Democracy Evolving: A Diversity of Institutional Contradictions Transforming Political Economy." *Journal of Economic Issues* 50, 4 (2016): 1003-1026.

Schotter, Andrew. *The Economic Theory of Social Institutions*. Cambridge, UK: Cambridge University Press, 1981.

Schrepel, Thibault. "Predatory Innovation." World Economics Association Conferences, No. 1-2017. Available at http://lawandeconomics2017.weaconferences.net/papers/predatory-innovation-the-definite-need-for-legal-recognition/. Accessed September 1, 2017.

Sen, Amartya. "Isolation, Assurance and the Social Rate of Discount." *Quarterly Journal of Economics* 81, 1 (1967): 112-124.

——. "Rational Fools: A Critique of the Behavioral Foundations of Economic Theory." *Philosophy & Public Affairs* 6, 4 (1977): 317-344.

Shackle, George L.S. *Expectations in Economics*. Concord, NH: Gibson Press, 1949.

Simon, Herbert. "The Architecture of Complexity." *Proceedings of the American Philosophical Society* 106 (1962): 467-482.

Solari, Stefano and Francesca Gambarotto. "Territorial Rooting as an Element of Wellbeing." *Review of Social Economy* 72, 4 (2014): 504-522.

Swann, G.M. Peter. *Common Innovation: How We Create the Wealth of Nations*. Cheltenham, UK: Elgar, 2014.

Taleb, Nassim. *The Black Swan: The Impact of the Highly Improbable*. London, UK: Penguin Books, 2007.

Tang, Yinan and Ping Chen. "Transition Probability, Dynamic Regimes, and the Critical Point of Financial Crisis." *Physica* A 430(C) (2015): 11-20.

Thornton, Tim. "The 'Complexity Revolution' Seen from a Historical and Heterodox Perspective." In *Reclaiming Pluralism in Economics*, edited by Jerry Courvisanos, James Doughney and Alex Millmow, pp. 238-250. London, UK: Routledge, 2016.

Tool, Marc R. *The Discretionary Economy: A Normative Theory of Political Economy*. Santa Monica, CA: Goodyear Publishers, [1979] 2001.

Valentinov, Vladislav. "Wiener and Luhmann on Feedback: From Complexity to Sustainability." *Kybernetes* 46, 3 (2017): 386-399.

Valentinov, Vladislav and Lioudmila Chatalova. "Institutional Economics and Social Dilemmas: A Systems Theory Perspective." *Systems Research and Behavioral Science* 33, 1 (2016): 138-149;

Van den Berg, Hendrik. "Mainstream Economics' Flight from Complexity." *Forum for Social Economics* (2016): doi:10.1080/07360932.2015.1028085.

Veblen, Thorstein. *The Theory of the Leisure Class: An Economic Study of Institutions*. New York, NY: Macmillan, 1899.

Vega-Redondo, Fernando. "Network organizations." *Journal of Complex Networks* 1 (2013): 72-82.

Velupillai, Vela, ed. *Computability, Complexity and Constructivity in Economic Analysis*. Hoboken, NJ: Wiley-Blackwell, 2005.

Velupillai, Vela. "The Impossibility of an Effective Theory of Policy in a Complex Economy." In *Complexity Hints for Economic Policy*, edited by Massimo Salzano and David Colander, pp. 273-290. New York, NY: Springer, 2007.

Ver Eecke, Wilfried. *The Concept of "Merit Good" and the History of Economic Thought: Ethical Dimensions of the Economy – Making Use of Hegel and the Concepts of Public and Merit Goods*. Berlin, Germany: Springer, 2008.

Von Bertalanffy, Ludwig. *General System Theory: Foundations, Development, Applications*. New York, NY: George Braziller, 1968.

Waldrop, Mitchell. *Complexity: The Emerging Science at the Edge of Order and Chaos*. London, UK: Simon & Schuster, 1992.

Watts, Duncan. *Small Worlds: The Dynamics of Networks Between Order and Randomness*. Princeton, Princeton, NJ: Princeton University Press, 1999.

Watts, Duncan and Steven Strogatz. "Collective Dynamics of 'Small-World' Networks." *Nature* 393, 6684 (1998): 440-442.

Weaver, Warren. "Science and Complexity." *American Scientist* 36, 4 (1948): 536-544.

Wilson, David. "Two Meanings of Complex Adaptive Systems." (Mimeo) Binghamton University, NY, 2014.

Wilson, David and John Gowdy. "Evolution as a General Theoretical Framework for Economics and Public Policy." *Journal of Economic Behavior and Organization* 90S (2013): S3-S10.

Witt, Ulrich. "Economic Policy-Making in Evolutionary Perspective." *Journal of Evolutionary Economics* 13, 1 (2003): 77-94.

Zeng, Weijun, Minqiang Li and Nan Feng. "The Effects of Heterogeneous Interaction and Risk Attitude Adaptation on the Evolution of Cooperation." *Journal of Evolutionary Economics* 27, 3 (2017): 435-459.