1. Policy and state in complexity economics

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1.1 SIMPLISTIC AND COMPLEX SYSTEMS AND POLICIES

Mainstream policy conceptions and prescriptions appear to be normative postulations for a permanent ‘state planning for more market’, mainly organizing ‘de-regulation cum privatization’, rather than deliberate sets of conditional recommendations based on pondering alternative potentialities and paths. Such crude normativity has dominated the world since the late 1970s. Furthermore, it is usually put forth tacitly, due to the attitude of T-i-n-a (‘There-is-no-alternative!’).

The economic conception behind such *crypto-normativity* is the idea of some unique (and optimal) equilibrium benchmark (point or path) related to a ‘perfect market’ that is derived from a rather simplistic model. The latter is custom-made to allow for analytically tractable solutions, with its ‘representative agents’, ‘optimal’ information and decisions, suitable functional forms, and equilibrating mechanisms, allowing a predetermined equilibrium, and thus a *teleological* attitude, which Veblen had already criticized (Veblen 1898; Foster 2006; also Fontana 2010; van den Berg 2016).

Stochastic versions, such as dynamic stochastic general equilibrium (DSGE) models, presume random stochastic processes (the notorious ‘Brownian motion’). Related statistical distributions of values and event sizes are thus always considered normal distributions. And rational expectations of clear-cut (and existing!) mean values (and comfortable variances as calculable ‘risk’) can then be used as justifications (Kirman 2016).

This, however, is only warranted either in simple (as indicated above) or in non-organized complex systems (Weaver 1948), the latter having great numbers of identical particles, whose properties and motions can be assumed to average each other out, as in early 19th-century physics for the prototypical gas in a container under static conditions. This presumption has also been used in stochastic neoclassical models, and related financial-sector models pre-2008 (the Nobel-laureated models of Black, Scholes and Merton). Economies, including the financial sector, however, are not 'non-organized' complex systems. These models, thus, turn out to be a cornerstone of the global financial crisis of 2008 and onward, as real systems, with their human agents systematically interacting, adapting, aspiring and anticipating under fundamental uncertainty, are precisely systems with so-called organized complexity (ibid.),[1] which behave qualitatively differently from random motions (Mandelbrot 1997; Lux and Marchesi 1999; Mandelbrot and Hudson 2006; Battiston et al. 2015; Tang and Chen 2015),[2] based on diverse complex self-organization mechanisms.

But self-organization capacities of 'organized complex' systems have justified, particularly along Hayekian lines, the making of redundant proactive policies, as they are theorized, under the assumption of a favourable information distribution in the 'market', to generate some relatively 'optimal' ('natural') 'spontaneous order' (for such a 'non-policy' towards the global financial crisis, see Lewin 2014).

But such self-organization capacities are, in fact, just any kind of systematic interactions of agents, whether appropriate or not (Kirman 1998b; Rycroft and Kash 1999: 90ff). Self-organization mechanisms do exist in both natural and social complex systems, from sand-pile and snow avalanches to tectonic plates' movements, from natural forest patches and related forest-fire sizes to frequencies of words in languages, from human territorial settlements, firm populations and financial sectors to all human agents' interactions in general. And the implications are severe.

As economies are also *open, metabolic systems*, self-organization may increase the systems' complexity, at the expense of their entire surrounding system (society, nature) – far *beyond optimality and predetermined equilibrium* – which refers to so-called *dissipative structures* or systems (Prigogine and Nicolis 1967). Such *complex adaptive systems* (CASs) display *dynamics* with transitions between some temporarily increasing *order* and often abrupt and volatile *disorder*, stasis alternating with turbulence, moving between complete information conservation in simple systems and extreme diversity generation (and information loss) in chaotic systems, mostly lingering 'at the edge of chaos' (Kauffman 1993; for economic CASs, see for example Bloch and Metcalfe 2011; Durlauf

[1] Please note that current complexity economics is in the tradition of older *general systems theory* (L.v. Bertalanffy) and *cybernetics* (Wiener and Ashby). For complexity ideas in the history of economic thought, see Elsner et al. (2015: ch. 12).

[2] There are, of course, many definitions and measures of complexity, based on, e.g., how difficult a system is to be described or reproduced, in terms of computational time or information bits (Lloyd 2001). We will not confine ourselves to a particular definition but focus on briefly describing complexity properties.

2012; Valentinov and Chatalova 2016). ‘Self-organized’ order and increasing complexity, thus, has little to do with equilibrium, ‘optimality’ or ‘natural’ states: ‘… 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’ (Colander and Kupers 2014: 5). So economic *policy*, in order to shape and influence economic CASs and their dynamics ‘for the better’, comes into play: self-organization does not release us from public policy (Room 2011). And it will have a qualitatively greater, and completely different, role to play than in a simplistic world.

Particularly in decentralized and deregulated spontaneous individualistic economic systems, called ‘market economies’, with their particular turbulences and incentive structures, mostly favouring a myopic maximizing (a ‘hyper-rational’ behaviour) (Aspara et al. 2014), ‘self-organization’ mechanisms do dominate that generate fallacies of aggregation in intricate decision-making structures, such as ubiquitous social dilemmas (Valentinov and Chatalova 2016),[3, 4] and a ‘pervasiveness of negative unintended consequences’ (Wilson 2014). Often, cumulative, positive feedbacks tend to shift the system towards some lock-in, often in inferior states (David 1985; Arthur 1989). This mirrors – besides cumulative and disequilibrating technological processes, such as increasing returns in production or network externalities in use – manifold information deficiencies, fundamental uncertainty and bounded rationality, cumulative behaviours (herding), power-related structures, or ceremonial (power- and status-based) degenerations of institutions.

Deregulated and globalized ‘markets’, with increasing volatility and opacity for individual agents, tend to generate some (perceived) over-complexity (of the individual decision situation) and over-turbulence, with well-investigated systemic costs (Helbing 2013; Mirowski 2013;

[3] We elaborated on the ubiquity and everyday relevance of this social dilemma elsewhere (for example, Elsner and Heinrich 2009).

[4] Valentinov and Chatalova develop a systems-theoretic explanation of the ubiquity of social dilemmas: Social systems inevitably are operationally somewhat closed towards their environment, but at the same time are metabolically dependent on it. Social dilemmas then originate from the conflict between these two systems identities, when systems disregard their environmental dependence. Economic incentives then are individual-level projections of systemic imperatives from their artificial closure, and social dilemmas then are explained in terms of excessive myopic economic incentives, which make individual agents insensitive to their dependence on their environment.

Battiston et al. 2015), unsurprisingly restricting the creativity and innovation capacities (and willingness) of individual agents (Vega-Redondo 2013).

Complexity Economics (CE)[5] suggests that, although self-organization mechanisms might shift a CAS into some stationary state (or so-called attractor), they usually will give rise to multiple equilibria, superior and inferior ones, often unstable and transient.

Particularly in 'market' economies, a required problem-solving self-organization, facilitating some stable superior attractor, namely some 'instrumental' institutional emergence in intricate incentive structures, may be (i) very time-consuming to come into effect, and (ii) fragile (prone to backslide), if not (iii) blocked entirely. Some system(at)ic policy vis-à-vis economic CASs, to push it into superior and stable areas or paths, is thus due.[6]

Properly elaborated complexity policies, then, particularly when focusing on proper institutions and institutional change, may improve incentive structures and other critical conditions of agents' behaviours, thus supporting problem-solving (instrumental) emergent social institutions. These may promote collective problem-solving capacities, stabilize the system's path, make it settle in a superior attractor, and generally improve its properties and dynamics (see for example Colandera and Kupers 2014; Gilles et al. 2015; Hu et al. 2015). 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 that has been the paradoxical consequence of the increasingly crisis-prone neoliberal era.

Since the global financial crisis, it has become obvious to an increasing number of economists (and practitioners) that we need different theories and models than those related to perfect agents and mechanisms, to 'smooth' process, and unique equilibrium. CE, in fact, is incompatible with the historical message of the mainstream that the 'market' economy tends towards a general and relatively optimal equilibrium and thus is the only way, vanishing point, and end of human history.

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[5] See for example Waldrop (1992); Arthur et al. (1997); Foster (2005); Velupillai (2005); Garnsey and McGlade (2006); Holland (2006); Beinhocker (2007); Miller and Page (2007); Mitchell (2009); Colander et al. (2011); Kirman (2011); Aoki et al. (2012) and Arthur (2013, 2015).

[6] Kirman (2016) assumes a more radical view against such policy optimism, arguing that attractors always change with evolution, undermining ameliorating policies. On top of that, we may argue, policy itself also changes such conditions. We will consider remaining policy options.

Complex models consider many and heterogeneous agents in recurrent direct interactions, within many different and intricate incentive structures, with different self-organization mechanisms and ongoing differential replications in an evolutionary process, and on different social and spatial topologies. They can only be applied, in the final instance, as agent-based models (ABMs) on topologies, using social network analysis (SNA). This, then, not only is no longer analytically solvable and can only be computed in complex simulations, but also demonstrates that we have to deal with completely different problems than predetermined optimal equilibrium – a true paradigm shift (Fontana 2010; Arthur 2015).

With its models and computation tools, its systemic and 'mechanismic' character, and its implications of mutual micro and macro foundations, CE has developed into a promising cross-paradigm that has the potential to serve as a common denominator for heterodoxies (Thornton 2016).

Policy implications of CE have become a major theme recently, naturally occurring with some time lag vis-à-vis its underlying paradigm (CE), and particularly boosted around the global financial crisis.[7] The present chapter will particularly refer to a well-known group of CASs, with repeated social dilemmas in an evolutionary game-theoretic (EGT) and an evolutionary–institutional perspective – the evolution-of-cooperation approach (Axelrod 1984 [2006]; Lindgren 1997; Kendall et al. 2007; Colander and Kupers 2014) – in order to derive some concrete policy orientations. However, we will not have the space to develop particular policy cases, such as financial sector reform.

Section 1.2 will briefly review CASs, addressing structures, mechanisms, critical factors and dynamic properties. Section 1.3 will consider some policy orientations from the CE literature. Section 1.4 will refer to the 'evolution-of-cooperation' and its policy implications. Section 1.5 will generalize and discuss policy implications derived from an evolutionary–institutional perspective on games on networks and populations with ever-changing fitness conditions. Section 1.6 will consider implied requirements for the state, with socio-political evaluations of system outcomes and related action, introducing the idea of 'new meritorics', coinciding with long-standing pragmatist/instrumentalist policy conceptions, and the qualifications the state itself would need to develop.

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[7] See for example Durlauf (1997); Hayden (2006); Salzano and Colander (2007); OECD (2009); Geyer and Rihani (2010); Room (2011); Dolphin and Nash (2012); Durlauf (2012); Fontana (2012); Morçöl (2012); Wilson and Gowdy (2013); Colander and Kupers (2014); Fontana and Terna (2015); Geyer and Cairney (2015) and Price et al. (2015).

1.2 PROPERTIES OF ECONOMIC CAS

1.2.1 Initially 'Given' Structure

In CASs, with a population of many heterogeneous interacting agents, some network topology, and games played on graphs, the model structure considered 'given' includes:

Decision structures Agents are directly interdependent and recurrently interacting in different, more or less 'intricate' (usually many two-by-two) decision problems (incentive structures). They are potentially heterogeneous as they have different behavioural/strategic options, some of which may be interactively learned in a process. The usual formal language here is game theory. We may think of different coordination, anti-coordination, non-(or dis-)coordination, and social-dilemma games. Different options then may generate (initial) strategic uncertainty in an ongoing process beyond hyper-rational behaviour, opening space for social learning of different behavioural rules and institutions (Schotter 1981). These then may become habituated and emerge under reinforcement learning, when interactions are indefinitely repeated, and a learned and habitually acquired longer time horizon substitutes initial short-termism. Other conditions for cognition, expectation building, and learning of coordination and cooperation, such as the fierceness of the quantitative incentive structure, interaction-arena size, the initial minimum critical mass of cooperators in the population, or agency capacities such as partner selection, are also important for modelling.

Network structure Those games may also be defined on different network topologies (Jackson and Zenou 2015),[8] defining a population with different social or geographical distances/proximities (neighbourhoods), with related differential probabilities to interact, and with implications for differential performance and behaviour diffusion (a classic neighbourhood model: Schelling 1971). Empirical network structures display different spatial centrality, clustering, and distance patterns. Neighbourhoods may be clusters within a larger network. There may also be overlapping and staged systems of clusters, where one agent may

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8 Note that we call the given (and later perhaps endogenous) topology of a population (a system of interaction arenas) a network, and an emerged platform of multilateral institutionalized cooperation will be termed an emerged network (Kirman 1998a), usually emerging in individual arenas and for parts of the population (a 'group', neighbourhood, firm cluster, or functionally defined field).

interact in different arenas in different social roles, for different 'goods' (with different overlapping and staged reaches for their part), in all so-called multilayer or multiplex networks (Cozzo et al. 2016). Further, agents may die, get born, learn and change strategies, imitate, or occupy behavioural niches, in response to their relative success, and when they are allowed to move in reaction to their relative performances, the network will become endogenous (Schelling 1971; Kirman 1998a).

Institutional structure and 'rules of the game' Initial structures are generally assumptions in a modelling method. Initially given decision structures, strategies, and network structures are not preset 'givens' in reality but are always evolved results of preceding historical processes. While even 'rules of the game' (for example, periodization of interactions, mutual rationality assumptions and other common knowledge, common time horizons, correct comprehensibility of actions, 'trembling hands', etc.) may be part of what we want to explain, they also are methodologically mostly required as givens – which of course implies cautious modelling strategies.

1.2.2 Process, Emergent Structure and Resulting System Properties

Continuing interaction, nonlinear aggregation and structural emergence Ongoing interactions, usually among intentional, learning and adaptive agents (or, in EGT, among strategies and their carrier groups), generate, already under simple conditions, some cumulation and non-linear aggregation, compared to linear summing-up of supply or demand quantities of representative agents. Agents will adapt to each other, their neighbourhoods, or to the global state of the system, and may imitate and herd, or cumulate in other ways. With non-linearities, the resulting structures cannot be traced back (reduced) to the properties of individual agents – the well-known phenomenon of emergence.[9]

Emergent 'macro' and 'meso' properties Emergent structure shows that boundaries between micro and macro blur. Empirical stochastic analyses of system behaviours (real-world or artificial) relate to both 'macro' structure and the 'micro' level (Acemoglu et al. 2015; Jackson et al. 2017), resulting distributional statistics are indicative of both micro and macro properties. And emergent macro structure feeds back to micro

[9] Capacities of structural emergence are considered *the* distinctive property of CASs, to be analysed in 'generative sciences' (Epstein and Axtell 1996; Harper and Lewis 2012).

behaviour and changes it (reconstitutive downward causation: Hodgson 2002). And when it comes to emergent structure and (cumulative) downward feedback ('macro foundations of micro'), the limits of analytical tractability and determinacy are quickly reached. Often it is also appropriate to focus on some 'meso' level (considered below the size of the entire 'macro' economy or population, as a constituent component of them), since informal structural emergence often occurs prominently at 'mid-sized' arenas, due to better cognitive and expectational conditions there (Elsner and Heinrich 2009; Dopfer 2011; Elsner and Schwardt 2014).

Path-dependence and non-ergodicity CASs are recursive not only among their components at one level but also among their micro, meso and macro levels (Dopfer 2011). While agents act under complex conditions (many interactions with many heterogeneous and adapting agents, differential replication and thus ever-changing socio-ecologies), with relatively limited cognitive capacities (bounded rationality), mostly only local experience, and fundamental uncertainty, searching, experimenting, reacting and adapting, the system will typically behave nonregularly and in a statistically non-stationary manner over time, or: in 'path-dependent' ways.[10] This may be consistent with the settling of the system (for some time) in some fixed point/attractor or its traversing of some (usually periodic) orbit. Path-dependent processes are sensitive to initial conditions, often vulnerable to small changes of initial conditions, and in this sense history matters (extremely so in so-called chaotic phases, where at some 'tipping point', or 'phase transition', we cannot even forecast in the short run whereto the system will go). Infinite recurrence, sequentiality of interactions, and infinite differential replication generate an 'open-ended' process over real/historical time (indefinite in time and in phases unpredictable in the short run). Such a cumulative process is irreversible, and at times becomes idiosyncratic, that is, unpredictable as already stated, as there are often multiple potential equilibria and paths, and in the extreme it becomes what is called 'deterministic chaos'. Such systems are non-ergodic in the sense that the distribution of states that they do assume over time is not identical to the distribution of potential states they basically could assume (judged from their structure). Thus, no normal distributions of system motions

[10] This requires that, in a nutshell, variables are time-dependent, in themselves (discretionary: $x_{t+1} = f(x_t)$) and among each other ($x_{t+1} = f(x_t, y_t)$ and $y_{t+1} = g(y_t, x_t)$).

with comfortable probabilities for forecasting exist, but rather a sensitive dependence on initial conditions.[11, 12]

Self-organization and persistent fat-tail distributions Self-organization capacities are reflected by surprisingly persistent empirical distributional structures of certain properties (centralities of agents, critical system motions). Certain stable centrality distributions may emerge, and some meta-attractor may even cause repeated system motions (such as financial crises) of a certain size distribution always back to it. We are talking about right-skewed statistical distributions, also called long-tail or fat-tail distributions. In 'market' economies, particularly the financial speculation sector, there are usually many agents with only a few relations, and very few with very many relations (or high centrality). The mechanisms at work have been considered as the rich get richer or preferential attachment (Barabási and Albert 1999). Individual problems of the most central and powerful may then cause large system crises, occurring with a considerably higher probability than suggested by a normal distribution. Of particular interest have been self-organization mechanisms that are so strict throughout the system that they display the same functional property at all levels. The functional form of the statistics, detected for the first time by V. Pareto for income distributions persistent across countries and centuries, are known as power-law or scale-free distributions, which have the same functional properties at all scales, indicating a self-organization mechanism working identically at different scaling – the phenomenon of self-similarity (also known as 'fractals'). Mapped as log–log, they become a linear curve. In many spontaneous decentralized systems – usually historically emerged, deep-rooted individualist cultures of market economies – human agents and firms differentiate in specific ways in terms of power and status. SNA and network statistics then reveal such long-tail or power-law distributions of degrees of centrality. They occur, as indicated, in diverse real-world areas, such as income and

[11] *(Non-)ergodicity* was adapted from statistical physics and stochastic processes of physical systems. Post Keynesians, for instance, have discussed the issue in connection with Keynes's conception of fundamental uncertainty and in distinction from the rational-expectations justification of non-intervention into the 'market' (Sargent and Lucas, see Davidson 1982/1983). Keynes, in his critique of early econometrics, with his argument of 'non-homogeneity' and 'non-stationarity' of stochastic process and time series, seemed to have an understanding of non-ergodicity (O'Donnell 2014; Rosser 2015/2016).

[12] In this context there is a recent interdisciplinary discussion of novelty, surprise, and fundamental innovation (see previously Shackle 1949). We cannot delve into this, but point out the nexus of rare events/surprise, fundamental uncertainty, sudden innovation and non-ergodicity (Heinrich 2016; Markose 2016).

wealth, firm size ('Gibrat's law') or spatial settlement (city sizes; 'Zipf's law'), word frequencies in languages, internet-sites size distribution, the size distribution of natural forest patches (and of related forest fires), the size distributions of sand-pile or snow avalanches, or of earthquakes. Some critical events (sudden movements, phase transitions) repeatedly make the system approach a certain state (a dominant or meta-attractor), as already stated, where the very continuous change of the system states after some major motion (crisis, avalanche, etc.) contributes to the repeated system movement towards that attractor, the so-called self-organized criticality (Bak and Tang 1987). Note that this also applies to capitalist cycles and financial sector crises in particular: If left alone, crises will reconstitute conditions (firm concentration, over-accumulation of capital, accumulation of cascades of securitized papers, etc.), under which the system again builds up towards its next crisis. Large financial crises do in fact appear considerably more often than expected in mainstream models of random process (Mandelbrot and Hudson 2006; Taleb 2007). In contrast to normal distributions, fat-tail distributions often have no (finite) mean, around which 'rational' expectations (of prices, events, etc.) of 'rational' agents might centre. Note that this has been exactly a long-standing issue of original evolutionary–institutional economics. The mechanism of emulation of higher social castes and of invidious distinction among those of the same social class, if operating at all social strata of predatory (capitalist) societies, was central from the very beginning of institutionalism (Veblen 1899). Such ceremonial self-organization would then trickle down through the entire society, and somehow homogenize it, reducing its resilience and sustainability.

Emergent small-world networks Topologies that display power-law distributions of nodes ('scale-free networks': Barabási and Albert 1999) usually display hierarchical structures of sub-graphs, and often hub-and-spoke-type sub-networks. More effective networks make a different use of central positions, combining local clusters and long-distance relations, so that central positions may play some role within local clusters, but mainly among clusters, at 'gates', where long-range relations to other clusters begin. So-called small-world networks (Watts and Strogatz 1998) facilitate, by their clustering, some local problem-solving through dense interaction and quick institutionalization, and at the same time display, through their long-distance relations, a relatively low mean path-length between any two agents in the entire network, ensuring relatively quick diffusion of information. Again, this all has little to do with optimality, as large nodes, such as persistent hubs, may still cause the problems mentioned for system stability and resilience. Central power positions, if not avoidable as such (gatekeepers), will need to be carefully controlled.

Lock-in, ceremonial dominance and collective-action capacities Intricate problem structures, such as social dilemmas, display mixed interests (partially consistent, partially conflicting), and under recurrence entail lasting tensions among agents. But even in relatively simple coordination games with Pareto-different solutions, a collective incapacity to ensure longer-run optimal solutions exists. As systems may run into technical and institutional lock-in (David 1985; Arthur 1989), this may be at an inferior technological and institutional coordination, which is indicative of differences between individualistic and collective rationalities. As rivalling technologies, innovation efforts and standard wars (under scale economies and network externalities) may be both coordination and dilemma games, institutional lock-in will be a reflection of dominant ceremonial aspirations of differential status and power. This may be considered some degeneration of originally instrumental institutions (emerged in repeated dilemmas), for instance through an increasingly unequal distribution of cooperative gains (Elsner 2012). In contrast, as long as strategies can be interactively learned and adapted as 'instrumental' solutions of coordination or dilemma problems, emergent structure assumes the form of problem-solving rules or institutions.[13] But in either case, social institutions are complexity-reducing devices. Whether instrumentally or ceremonially warranted, they generate some stability ('homeostasis') and ensure some continuity. In the ceremonial case, this may be some 'hysteresis'; in the instrumental case, they will generate some progressive adaptability (Bush 1987).

Individual agent capacities, intentionality and institutionalization EGT-based evolution-of-cooperation approaches assume many sequential two-person games in a population, calling for making implicit agency capacities (beyond hyper-rational maximization) explicit. In order to solve Prisoners' Dilemma super games (PD-SG), agents must culturally acquire longer-run perspectives (see below). As behavioural innovators

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[13] On terminology: coordination problems are solved by common, coordinated behaviour through the device of learned social rules, while social dilemmas (requiring the sacrifice of the short-run maximum for solution) are solved by collective cooperation through the device of learned social institutions (learned in indefinitely repeated interactions). An institution, then, is a social rule plus an endogenous sanction, with the credible threat of a punishment (with costs for the punisher), as exerted by a memorizing and provokable trigger strategy, such as, in the simplest case, tit-for-tat (Schotter 1981; Axelrod 1984 [2006]).

and initial cooperators in a defective social environment, they must be risk-taking (in the sense of being vulnerable to exploitation) and not too envious, should have some capacities of memory, monitoring, and reputation-building and -using, capacities of preferential mixing (partner selection) or establishing and terminating relations, and, in the spatial case, of moving into and out of neighbourhoods. Further, in multi-agent and multi-strategy environments, where transparency and cognitive capacities may quickly be too small, and perceived complexity and volatility too high to behave in a globally rational way (Durlauf 2012), agents must be both searching (experimenting, adapting) and endowed with some intentionality to improve their outcomes, to solve intricate common or collective problems,[14] and to reduce perceived complexity. This is where the rules and institutions come in, and Veblen's instinct of workmanship or idle curiosity would seem to apply as motivations to search, experiment and learn cooperation after repeated frustration from the results of the one-shot logic.

1.2.3 Performance and Replication: Cumulation and Endogenous Networks

Differential performance and replication, fixed points, attractors, orbits
Agents (or strategies) in a population with repeated encounters will have performed differently after many interactions within a 'round' (an SG), and after many rounds played with many different agents, at the end of an (artificial) 'generation'. A replicator mechanism generating differential 'offspring' according to performance, also considered learning or imitation vis-à-vis some reference (average or maximum in the population, some peer group or neighbourhood), will provide a next 'generation' with a different social ecology, a changed strategy composition of the population. And with continuing replication, we may generate a fully fledged evolutionary process (early simulations: Axelrod 1984 [2006]; Lindgren 1997). Replication processes may, under certain constellations, converge to one out of multiple possible fixed points (however, unstable and transitory; analysis of dynamical systems will show whether such equilibrium is stable or not). If unstable, the system may perform cyclical

[14] Coordination games are solved in the immediate interest of individualistic agents, through coordination by a social rule, which is just common, parallel behaviour. In contrast, the more intricate social dilemma, with its dominant incentive to defect and exploit, requires cooperation, through long-run rational behaviour, habituated and semi-consciously applied as an institution, a social rule plus the threat of sanctioning and falling back to the Nash equilibrium, and in that sense is a collective phenomenon.

(periodic) or even non-periodic orbits, but usually it will perform recognizable behavioural patterns.

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 meliorate the system. However, this is typically not the condition of complex dynamic populations (an older Veblenian insight was that there are no automatic 'meliorative' tendencies). In particular, when 'fitness' and population shares of the 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, the *s*-shaped logistic function), and thus are dependent on population shares achieved before, situations of a survival of the first, survival of the 'fattest', or a survival of all (with possibly different shares of each strategy) may occur (Nowak 2006).

Circular upward and downward causation The evolution of CASs is, as already stated, not just bottom-up emergence but also downward causation (reshaping incentive structures and behavioural patterns). Circular cumulative feedbacks have been mechanisms known in evolutionary institutionalism from Veblen through Myrdal, as well as in other heterodox orientations (Berger and Elsner 2007; Thornton 2016).

Endogenous network structure As mentioned, if, in an ABM on a topology, agents, after some 'generation' ended, may accordingly establish or terminate links or move into some other neighbourhood, the network structure will become 'endogenous' (Schelling 1971; Jun and Sethi 2007; Berninghaus et al. 2013).

With such basics of a complex evolutionary process we are 'maturing to a point at which policy implications are emerging … . Moving forward, it is our hope and expectation that … [this – WE] will greatly aid in the understanding of policies …' (Jackson et al. 2017: 41).

1.3 POLICY ORIENTATIONS FROM SOME COMPLEXITY LITERATURE

Manifold non-optimalities and shortcomings of structures, mechanisms, processes and other system properties, thus, result in some perceived over-complexity and (over-)turbulence, inferior system states, and insufficient dynamics, not properly reflected by the mainstream theory of 'market failure' (Fontana 2012). They require a proactive, systemic, often massive and persistent, but also adaptive and learning, policy intervention. Much has been developed already for such 'complex adaptive policies' in recent years.

1.3.1 'Revising the Concept of Regulation'

The analysis of CASs, as indicated, suggests a very different conception of 'regulation' than the economic mainstream has established. As sociobiologist Wilson (2014) argues, 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', while for complexity sciences,

> all of the metabolic processes that keep organisms alive and all of the social processes that coordinate … [social animals – WE] are regulated … . The concept of regulation in economics and public policy needs to be brought closer to the biological concept of [self – WE] 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' … (Ibid.: 11)

Then, 'the selection of self-organizing regulatory processes' (ibid.: 12) and their improvement become the major task. If appropriate policies would not be developed and engaged for the regulation of a CAS, the system would be exclusively self-regulated by some deficient mechanism.

1.3.2 Policy System Partly Endogenous

Public policy is itself a complex system with its own relative structural, procedural and performative strengths and weaknesses, but when interacting with its target economic CAS, it will have to develop a certain minimum degree of complexity. And it is to be considered (partly) endogenous to the CAS under its scrutiny and control, as it needs to be adapted according to the evolutionary dynamics of the target CAS. Such endogenous control may cover a bandwidth of impacts from a temporary non-reaction of the system through some policy evasion of its agents, preventing the system from properly reacting, to a hyper-reaction in a way that policy not only directly shapes it in intended ways but may also change the very conditions, mechanisms and dynamics under which the policy was initially made. This twofold impact may still produce the intended effects, but the second type of impact might also counteract the intentions.[15] The policy agent needs to take the double impact into account and consider that the foundations of its decision-making may be altered through its very action. This is typically the case when mechanisms and structures, for example, distributional, institutional and network structures, will be affected. With proper consideration, policy intervention could be made even more effective.[16, 17]

But the policy system must keep itself sufficiently exogenous to, and independent of, the target system, and can do so if it deliberately develops its different independent constitutional mechanism: uniform, transparent and (de)centralized public participative discourse and decision-making, informed of the complexity and properties of the target system (and of its own complexity). With this, some superior collective r*ationality* may become effective (Elsner 2001), then 'moving the economy from an undesirable basin of attraction to a more desirable one' (Colander and Kupers 2014: 53).

[15] As a methodological reflection of such endogeneity in an evolutionary–institutional framework, Hayden (2006) developed the Social-Fabric-Matrix approach to investigate network structures among agents, institutions, value systems and the policy system. The approach has often been applied to policy issues and helped pursuing policy impacts throughout the socio-economic system, with results often counterintuitive from a simplistic perspective.

[16] While Kirman (2016) suggests that such policy is impossible, as (superior) attractors always change with the system, policy intervention may make the case even worse. But we will stick to the more optimistic argument (shared by Colander and Kupers 2014) that proper and careful self-reflection of policy and its primary and secondary impacts may keep options toward improvement open. It is supported by cutting-edge methods of forecasting for CASs (Markey-Towler 2016).

[17] While 'imaginative' crucial decisions (Shackle), taken by private agents under fundamental uncertainty (but certainly institutionally shaped; for example, Keynes's 'animal spirits'), may contribute to the system's non-ergodicity, this may also apply to measures of the policy agent, which may destroy the very conditions in place when the decision was made. While this double impact involves the political control system further into the target system, making it more intensely 'endogenous', policy might become more effective when its instrumentation can make use of both channels of influence. This will usually be the case when it systematically implements structural/institutional change, changing the conditions of individual human agency (the second channel).

1.3.3 A Higher Complexity of the Control System

An early insight from information and control theory was that the complexity of a control system needs to be at least as high as the complexity of the target system ('Ashby's law': Ashby 1956), where only variety of the control system can 'absorb' variety of the target system. In order to shift a controlled system into an aimed-at area of outcome, while dealing with sometimes unpredictable adaptations of that system, the control system must be able to assume at least as many possible states or, equivalently, have at least as many degrees of freedom, as the controlled one.

But cause and effect between target and control systems can no longer be considered simple, unidirectional or structurally constant. For instance, a reversal of earlier policy will usually not generate proportionate reverse effects. For instance, institutional collapse will not take place at the same parameter constellation where institutional emergence occurred, due to, for example, hysteresis effects. Nor will the strengths of effects of identical measures be the same over time. Thus, the 'complexity-policy' system not only needs to be more complex, but also process-oriented, with a long-run learning and adaptation perspective – policy as a collective learning process (Witt 2003). It needs to be prepared to assume different states for the pursuit of its objectives.

1.3.4 'Reducing Complexity'

Proper complexity reduction is a major complexity-policy issue. We have 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 individual decision situations become less complex, for example, through institutionalization.

With respect to system complexity, many have warned recently against increasing instability and uncontrollability under increasing (over-)-complexity and (over-)volatility of globalized and financialized networks (see Helbing 2013; Mirowski 2013) and argued that, to make that system manageable, a fundamental redesign (Helbing 2013) is needed. One of the standard devices is already provided by some modularization into sub-systems, considering that some decomposability of CASs usually exists, through their very historical emergence from simpler and smaller systems (Simon 1962).

According to Loasby (2012), appropriate deliberate (re)modularization of today's real-world economic and financial CASs is to be based on a more selective connectivity (neighbourhoods, clustering, localization, smaller arenas and layered arena systems; also see partner selection), rather than further pursuing the ideal of a globalized 'total' connectivity into anonymous and obscure giant arenas. But modularization, or delinkage (Mirowski 2013), particularly urgent for the over-sized, leveraging and 'herding' financial sector (ibid.), 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 ('goods'). The issue applies to many current trends and discussions, such as the usual firm clusters and networks, shrinking and 'balkanizing' of the internet, peer-to-peer money and credit systems, local sharing economies, etc. Maintaining the system's resilience requires such modularization into cognitively appropriate arena sizes and the maintenance of their diversity (Biggs et al. 2015). But a simple system is certainly not a vanishing point of proper complexity reduction.

Thus, the issue stretches not only along the dimension of complexity reduction or increase, but also along the dimension of volatility and crisis vulnerability, so it is about proper selective connectivity and (de)linkage. Current regressive political reactions and votes of people against globalization have gone astray and against a system with ever more uneven distribution of income, wealth, power and centralities, and reflect such structural aberrations of CASs that have become over-complex, over-turbulent and over-obscure.

Given CASs' often discontinuous behaviours, reducing the system's (over-)complexity and (over-)volatility, preventing it from entering chaotic phases, may be more or less successful in different system phases, as CASs may be more or less policy-robust or sensitive at different times. If the system is in an inferior 'basin of attraction', interventions may have to be very massive and enduring to have even a little effect. In other phases and areas of the system, 'nudges' may serve the purpose.

With respect to the decision situation of individual agents, emerged collectivities (emerged networks or platforms) of cooperative agents reflect emerged social institutions, thus some complexity reduction (Bloch and Metcalfe 2011: 85f). Policy support for instrumental institutional emergence will then help reduce perceived (over-)complexity and turbulence, better reconciling complexity levels with agents' cognitive capacities. This may also help reducing myopia/short-termism and support a culture of farsightedness and, thus, an easier willingness towards (behavioural, technological) innovation.

As indicated, under enforced volatility, the reaction of agents, paradoxically, may be switching to higher rigidity, as agents can no longer properly organize search and learning – and the entire system will likely slow down (Vega-Redondo 2013). This appears to be consistent with some Polanyian protective countermovement against the deterioration of conditions of individual decision-making through increasing 'marketization' and deregulation. This may also explain many current petrifactions (including institutional lock-ins and ceremonial degenerations of institutions) in response to deregulation and 'flexibility'.[18]

Policy, then, through complexity reduction by some selective connectivity, delinkage and modularization may de-block, accelerate and stabilize processes of emergence of new institutions, thus enabling and empowering agents.

1.3.5 'Non-Algorithmic' Policy Measures

While the analytical intractability and often unpredictability of CASs quickly occur with increasing complexity (mirrored in model building from simple components, say, a 2×2 game, to a fully fledged evolutionary model), computation and simulation requirements obviously are much higher for CASs than for simple systems. But although formal methods are more demanding (dynamical-system analysis, SNA, ABM simulations), forecasting 'to the point' and related technocratic hopes of quick and easy 'manageability' (point interventions for to-the-point outcomes) will be infeasible. Policy interventions, therefore, have been said to remain 'non-algorithmic' in some critical instances (Velupillai 2005; 2007). Policy then will have to be more inductive and experience-based, and required continuous adaptations suggest a 'change in the worldview that is currently dominant in policy circles' (Velupillai 2007: 275). We sometimes can say only that a massive (institutional) change is required to push the system out of an inferior attractor but will be unable to forecast the system's exact reaction (considering, for example, policy evasion or deeper 'secondary' structural impacts, as mentioned). But such difficulties do not absolve politics from the requirement of adopting and maintaining a strong proactive role (Velupillai 2007; Durlauf 2012: 62ff). Drafting such 'complexity policy' justifies Colander and Kupers's (2014) dictum of a complexity-based 'art of public policy'.

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[18] We have argued elsewhere that in large anonymous and/or highly mobile/turbulent populations with frequent random partner change, agents may tend to stick to a PD-SG with the same partner as long as possible, or to 'meet again' (the same) more often, as far as such preferential mixing is feasible to them (Elsner 2005; Elsner and Heinrich 2009).

1.3.6 Further 'Complexity Hints for Economic Policy'

Salzano and Colander (2007) pioneered on policy implications of CE. One group of authors in their volume, Gallegati et al. (2007) focused on power-law distributions of firm sizes and argued that system stabilization under power-law structures has to control the 'idiosyncratic volatility' caused by certain motions of the largest firms (the 'tail risks'). They concluded by pursuing a reduction of high firm centralities and concentration, particularly by reducing certain legal protections of size and power (namely 'intellectual property rights'), which appears to be a quite traditional policy reform orientation similar to the pragmatist policy tradition (see below).

There still seems to be room for a closer look at a specific set of CASs, when striving to advance exemplarily specified policy orientations, measures and tools. While these, then, still appear barely operational (partly because never practised), they can verifiably be related to some model base and may open up further policy perspectives.

1.4 A SIMPLE EXAMPLE OF A FRAME-SETTING POLICY FOR INSTITUTIONAL EMERGENCE AND CHANGE

1.4.1 The 'Evolution of Cooperation' Approach

We refer to Axelrod's (1984 [2006]) approach to the evolution-of-cooperation in PD-SGs, a simple formal reflection of his early complex multi-strategy simulations. This has triggered a surge in the use of PD-SGs and simulations ever since (for an overview, see Kendall et al. 2007). It bears some exemplary policy relevance. But only an evolutionary–institutional interpretation, considering network structures and games on graphs, will provide some more far-reaching policy implications (see Section 1.5).

The well-known starting point is the PD normal form:

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

with $b > a > c > d$ and $a > (d + b)/2$.

The approach to the superiority of cooperation, in the sense of an evolutionarily stable strategy (ESS), in a population with randomly matched agents playing 2×2-PD-SGs, applies one of the usual ESS conditions of EGT, comparing defectors' (ALL-D) yields against tit-for-tat (TFT) cooperators with what cooperators attain playing against their kind.[19] The approach of an SG is the current capital values of related payoff streams compared ('single-shot'):

$$P_{TFT/TFT} = a + \delta a + \delta^2 a + \ldots$$

$$= \frac{a}{1-\delta};$$

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

$$= \frac{c}{1-\delta}; + b - c.$$

The ESS criterion used here is whether an existing population of cooperators can (or cannot) be invaded by defectors and thus be an ESS. 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 to prevail in a population, which however is to be embedded in an interpreting narrative.[20]

The critical condition here is the combination of EGT with SGs, that is, recurrence and culturally acquired time horizons. Such cooperation not only is infeasible under one-shot hyper-rationality (myopia) and

[19] TFT, as it is known, is the simplest cooperative strategy in a PD-SG that reflects the sequence of interactions (with one period memory), thus is responsive and therefore not always strictly dominated (as ALL-C would be).

[20] The related question for a population of defectors to be invaded by TFT cooperators is: What would the minimum critical mass of TFT cooperators be that can invade, survive and expand in a defector population and take it over (Axelrod 1984 [2006]; Elsner and Heinrich 2009).

would not be an ESS in regular EGT, but may attain ESS status in SGs with emergent proper cognitive conditions and expectations, indicated by the discount factor δ. The latter is equivalent to the expectation of meeting the same agent again next interaction, that is, recurrence. In a population, it is also equivalent to meeting any 'knowing' third agent, who may be informed about my earlier behaviour (through monitoring, memory or a reputation chain), or, even more generally, with the experienced general expectation (general trust) of meeting a cooperator. In a sequential (evolutionary) interaction process, this would require social learning and cultural acquisition of a related longer-run perspective (a higher δ). A question for more complex modelling, then, is the actual emergence of such longer-run rationality. The higher δ then indicates a high (perceived) probability, in any particular interaction, that the interaction will continue with the same partner (or a 'knowing' or generally cooperative one).

Habituation of cooperation as an institution may (and must) emerge, as agents must 'irrationally' sacrifice their short-run maximum, *b*, then receiving *a* (their sacrifice being *b* – *a*). The institution then solves the PD-SG through establishing habituated cooperation, being a social rule plus an endogenous sanction mechanism for not sacrificing (exerted through the credible threat of a trigger strategy, such as TFT, to defect upon defection and in this way punish the defector, even with cost for herself). 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 one-shot Nash equilibrium). As persistently hyperrational agents would play a series of one-shots, it must become habituated and pursued semi-consciously, by 'rational fools' (Sen 1977), that is, pursued as a rule as long as there is no reason to expect that in the next interaction the partner will intend to exploit.

In the evolution-of-cooperation approach, there have emerged a great number of elaborated models and approaches that have analysed further conditions of evolving cooperation. Just to mention two: With a potentially infinite number of strategies that can be ever further elaborated by agents, ever more sophisticated cooperative strategies may emerge (and will more or less dominate; see for example Lindgren 1997 and follow-up simulations). Second, clustered topologies will overall be advantageous for institutional emergence (for example, Watts 1999).

1.4.2 Some Immediate Policy Implications

A solution will transform the PD into a coordination game with two Pareto-different equilibria, and a policy perspective for the solution of a social coordination problem was already presented by Sen (1967). In the context of an endogenous national development strategy and a related collective saving effort of a population to build a national capital stock, he introduced into a stag-hunt game (which will not be solved under general distrust) the idea of a public assurance that all agents will contribute to the capital fund, and forego current consumption and increase saving to build that fund, in order to make the next generation (and not only one's own offspring) benefit (known as the 'assurance game'). A credible public assurance of even loads for all would be equivalent to an informal *contrât social* (Rousseau, who had introduced the example of the stag hunt in 1762), or a general-trust-building that in fact all will contribute evenly in order to yield the Pareto-superior coordination.

But as long as agents remain uncertain, hyper-rational and myopic, the superior, instrumental solution may remain completely blocked and the system caught in the one-shot Nash logic. Also, its emergence may be very time-consuming. Finally, an actually emerged instrumental solution may be fragile and prone to backslide and later breakdown, depending on the parameter settings and paths of evolutionary processes. Thus, there are more requirements for policy support for improved self-organization and faster and more stable institutional emergence.

As already shown by Axelrod, some policy support is immediately warranted, even on the basis of such a simple exercise:

1. According to the inequality above, one had to gradually improve the quantitative incentive (payoff) structure in favour of cooperation, reducing the fierceness of the PD, for example, rewarding common cooperation ($a\uparrow$), punishing defection ($b\downarrow$, $c\downarrow$), reducing the costs of common cooperation $(b-a)\downarrow$,[21] increasing the frustration $(b-c)\uparrow$ (which implies c will decrease more strongly than b, $c\downarrow\downarrow$), in all, weakening the dilemma. This would make the structure less intricate and difficult to be solved in a process, without necessarily dissolving the PD structure as such (which would be static and theoretically trivial). Formally, it is about reducing the right-hand side of the above inequality, so that

[21] Which, however, is highly uncertain among equally 'clever' agents, who will get (c, c). Thus, costs in fact often are $(c-a)$, which in fact is a gain for all.

the probability of realization of the superior, instrumental solution in an evolutionary process increases. Practically, this may be addressed through non-pecuniary payoffs from the public agent (such as, for example, selective early provision of exclusive critical information to cooperating private agents), while, on the other hand, providing pecuniary subsidies to generate a sufficient level of cooperation in sufficiently short time periods might be fiscally very costly.

2. Promoting the recognition of interdependence ('recognized interdependence'; see for example Bush 1999) and, particularly, the awareness of the common future, enlarging the time horizon through social learning ('enlarging the shadow of the future': Axelrod 1984 [2006]: 126–132). Technically, this renders the inequality above more likely to hold from its left-hand side. A culturally acquired longer-run perspective (formally, a longer-run calculation), to emerge as some enlightened self-interest, would then support institutionalized cooperation. This policy complex has also been an older institutionalist recognition, extensively dealt with as futurity by Commons (1934) (also Jennings 2005 on a 'horizontal approach'). Axelrod already gave policy examples for this, such as involving agents in a series of common projects that overlap over time, so that agents always have a perspective to 'meet again' (also Elsner 2001 and 2005, confirming that regional networking on identifiable collective issues through overlapping projects, as well as the public assurance that all relevant agents evenly contribute, may serve here).

This can, in general, 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 behaviour to make cooperation the individualistically dominant behaviour. Private agents not only need to be held liable for their individual interests in the collective solution (as indicated by the payoffs a), rather, they should correspondingly contribute. And their voluntary contribution should be 'intrinsically' learned and emerge in a process among themselves – rather than being imposed on them (or provided in lieu of them) by the public agent. Then, any gradual improvement of conditions will increase the probability of attaining a social solution in a process.

The public policy agent then needs to care that emergent private solutions will indeed be consistent with defined public concerns, that is, by supporting the instrumental solution through the private agents, these would be enabled to provide a collective good with a public good dimension, rather than colluding at the expense of third parties or of the general public (like a cartel).

The single-shot solution may be elaborated for some maximum size of population and some minimum cooperators' share, providing cognitive conditions with proper expectations 'to meet (again)' (Elsner and Heinrich 2009: 848, passim). Arena and platform sizes, thus, are another strategic factor for policy.

1.5 MORE POLICY IMPLICATIONS FROM THE 'DEEP SIZE STRUCTURE'

1.5.1 An Interactive 'Framework' Approach

The examples above reflect a more general principle of 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 be able to implement conditions for longer-run individual and collective rationality, for a better collective-action capacity, controlling the private interaction system in order to mitigate systemic failure and improve the system's path. However, there is no reason to assume the public agent, even a sophisticated and qualified one, will 'know everything' or always 'know better'. Rather, the complex behaviour of CASs suggests that the policy agent should also make use of the knowledge and adaptations of the private agents to steer, improve and stabilize the system. This we may qualify as specific frame-setting policy, letting the interaction systems of the private agents do their adaptations.[22]

Such a specified framework approach, based on an interactive relation between diverse bodies and levels of knowledge and action, has, somewhat misleadingly, been called 'activist laissez-faire policy' (Colander and Kupers 2014: 214ff) or 'political stewardship' (Beinhocker 2012; Hallsworth 2012; Colander and Kupers 2014: 240ff). More appropriately, it is a 'norm influencing role for government … designed to influence the rules … of the social game', and then government may indeed become 'a means through which individuals solve collective problems' (Colander and Kupers 2014: 186).

[22] This seems to resemble simplistic mainstream perspectives. However, it has little to do with just pushing the 'market' into a one-size-fits-all legal framework and then just letting go.

1.5.2 Inferable Policy Orientations

This approach includes identifying mechanisms and critical factors that generate the visible complex system motions, and complexes of policy tools addressing them. Based on the discussion so far, these will include:

1. *recognized interdependence*: fostering the awareness, on the part of agents, of a recurrent, and often intricate, interdependence structure among them;
2. *incentive structures*: identifying their kind and quantitative strength (type and degree of 'intricacy' of games): gradually improving them from 'fierce' to less 'fierce', 'intricate' to 'less intricate', leaving agents to adapt accordingly;
3. *futurity*: supporting private agents' cultural acquisition of longer time horizons;
4. *interaction arenas*: designing their sizes and structures, supporting emerging platforms of cooperation with their carrier groups, and their particular network structures;
5. *collective goods*, including natural and social commons, to be 'produced' (or reproduced) in those arenas and emerging platforms by way of cooperation: identifying their reaches, overlaps and layers, identifying their multiplex structure;
6. *deficiencies of the spontaneous decentralized private social provision processes*: identifying them in terms of potential complete blockage, excessive time requirement of emergence, and fragility (danger of backslide);
7. *public social and political objectives*: identifying the public-interest dimension in those collective goods, to be clarified in a proper legitimate public process;
8. *private interests in those solutions* (goods): identifying payoffs private agents may get from cooperation, in order for the public agent to call the privates in to contribute accordingly.

1.5.3 Further Policy Orientations, Considering Games on Networks

By elaborating on these policy components, in a 'games on graphs' perspective, further orientations may be derived. We will give a brief overview of some conclusions from the literature here. There are obvious overlaps among the following orientations, which indicates that effective results might be expected from a more systemic context to be generated for them:

Improving incentive structures, assuring, and supporting social focal points Both public assurance and making incentive structures less fierce may help agents to converge on superior coordination. For instance, applying the single-shot solution, it will be obvious that in financial-sector PDs, the short-term payoffs from one-sided defection are usually so large in relation to potential cooperative payoffs that an evolutionary, learned cooperative solution in the public interest can never be expected considering mere size orders of numbers. The public agent thus would have no other choice than to drastically reduce the leverages attainable through financial speculation and one-sided exploitation, in order to stabilize the system. In solved PD-SGs, transformed then into coordination structures, public activities, including assurance, may work to create a Schellingian 'focal point' for some superior coordination (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: Both arena sizes and network structures need to become issues of public policy, with a focus on local clusters, selective long-range interconnections, multiplex structures, and resulting 'macro' properties of the entire network of a population (Kirman 1998a; 1998b). Small-world structures need to be optimized, and central positions controlled and regularly exchanged among agents, since 'the more knowledge we have of how people are connected on the relevant network … the more chance a policy has of succeeding' (Ormerod 2012: 37). For instance, supporting small-world properties, while avoiding too much centrality and power for only a few, may render distributions more even and less volatile (their graphs steeper). Conversely, when regulating connectivity structures, the small-world property may not be suspended. Reducing high level power positions should help stabilize systems and increase their resilience (Gallegati et al. 2007; Acemoglu et al. 2012; 2015; Biggs et al. 2015).

Network structure II: shaping the system of interaction arenas Interaction arenas and cooperation platforms of proper sizes, overlaps, and hierarchy levels need to be considered, since they further shape cognitive and expectational conditions. Such structures will have to mirror the overlapping and layered reaches of the basic collective goods and functions, and the state structures need to coevolve appropriately (Faggini and Parziale 2016, on coevolutionary state structures). This implies supporting local, regional, national and global collective goods production through 'structural' (industrial, regional, environmental, developmental, etc.) policies (Chertow and Ehrenfeld 2012). Generating proper meso arenas would help to better meet cognitive capacities and increase private problem-solving capacities (Loasby 2012; Charness and Yang 2014). Many analytical, empirical, simulation and lab approaches have shown that smaller arenas within larger topologies promote recognized interdependence and futurity, and with this the quality of private decision-making (Richards 2012; Mirowski 2013; Vega-Redondo 2013; Elsner and Schwardt 2014; Kao and Couzin 2014). This also applies when agents can make voluntary location choices, that is, spatial partner selection (Berninghaus et al. 2013).[23]

Reducing turbulence by reducing the disembedding of mobility Reducing perceived over-complexity and over-turbulence is also related to providing proper time frames and some deceleration, required to learn, adapt, habituate and stabilize expectations and relations (Houser et al. 2014; Acemoglu et al. 2015). One particular implication – most obviously running counter to established neoclassical and neoliberal convictions, but making much sense within an evolutionary–institutional interaction perspective – is that such social-capital-building may require the reduction of current levels of (enforced disembedding and uprooting) mobility that was so crucial for 'flexibility' in the neoliberal narratives, but which usually contributes to high social costs (Glaeser et al. 2002; Room 2011; Solari and Gambarotto 2014).

Strengthening agents' capacities Strengthening agents' capacity to deal with intricate problem structures requires that they be provided with improved information on their interaction histories (memorizing: Houser et al. 2014). Providing sufficient time for social learning (general deceleration) should also support capacities to memorize, monitor, build reputations, use reputation chains, and with such information to select partners. Policy should also support agents' risk-taking, for trying to escape social dilemmas, and non-enviousness, should first cooperators be exploited once (which they can never make up, even if cooperation begins thereafter), further, searching and experimenting, in order to generate cooperative minimum critical masses required to make cooperation superior overall and spread.

Informational openness and multiple-path creation Originally instrumental institutions may, due to their very habitual character, degrade into

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[23] This is of course difficult to police. We made some more operational considerations of shaping arena sizes for the case of rural-to-urban migrant workers in China elsewhere (Dai and Elsner 2015).

abstract norms and ceremonial devices, removing themselves from problem-solving when the original problem situation has changed. For instance, with cooperation gains unevenly distributed, a new social dilemma may emerge with the same institutionalized, but now 'petrifying' behaviour. Proper institutional renewal may be less rewarding in the beginning than the old institution, while superior in the longer run (Elsner 2012; Heinrich and Schwardt 2013). Restoring agents' problem-solving capacities and promoting progressive institutional change will then require some break-out from institutional lock-in. This, in turn, may require some information openness. A multi-standard or technological-diversity policy, breaking up behavioural (as well as technological) standards, may be required. However, this may not always be feasible under returns to scale and network externalities. So there are critical conditions for new institutional solutions and standards to be learned and for openness and transition policies to become feasible, and they may exist in critical time windows only (Heinrich 2013; 2016; Houser et al. 2014; Papachristos 2017).

Favouring equality It has been widely analysed in interaction models that favouring equality among agents is a warranted policy orientation (Hargreaves-Heap 1989; Binmore 2011: 165ff; Kirman 2016: 563ff). Asymmetric payoffs usually increase intricacy and volatility, through continuing income-distribution battles, distracting agents' resources from problem-solving and common wealth creation. It appears also from experimental analyses that more even payoff structures are easier to solve for agents, thus more stable in the longer-run, and facilitate voluntary collective-good contributions (Kesternich et al. 2014; Krockow et al. 2015; López-Pérez et al. 2015; Nishi et al. 2015), in this way also increasing macroeconomic performance and perceived welfare (Acemoglu et al. 2015).[24]

1.6 'NEW MERITORICS', PRAGMATIST POLICY AND THE QUALIFICATION OF THE STATE

The framework approach, as laid out, is about shaping constellations for CASs that entail particular adaptive processes among interacting agents

[24] As we have not dealt with evolutionary macro models with their aggregate agents/components, we will not delve into *macro policies* here. But this is another area of applied CE and complexity policy (see for example Garbellini 2016, on complexity reductions in fiscal policy vs neoliberally generated over-complexity).

with dynamics and emerging structures in favour of superior outcomes, consistent with broad socio-political goals. It is doubly interactive in the sense that it interacts with a CAS and targets the interactions system and self-organizing mechanisms among the private agents. As it is targeted towards institutional structures, we may also call it institutional policy. It provides a clearer definition of the relative private and public interests and a more appropriate assignment of the relative private and public responsibilities and contributions, as compared to conventional collective-good theory. In current policy practice, the latter often leads just to bailouts of the big tail risks, to opaque 'private–public partnerships', and to thriving, but obscure, interventionism.

In this framework conception, the policy agent needs to evaluate the outcomes of the private interaction processes: what are the dynamic deficiencies of the system, their reflections in deficient self-organization mechanisms, and their outcomes? Evaluation criteria will be, as already stated, the probability of complete blockage of aspired institutional emergence and change, the time required for emergence or change, and the degree of its fragility. Policy, then, is to unlock/de-block, accelerate and stabilize emergence. The traditional merit-good criteria of 'wrong' price and quantity (Musgrave) will be extended in view of CASs by the above criteria. Thus, we may speak of a 'new meritorics' (Elsner 2001; Ver Eecke 2008).

This, in turn, requires a 'strong' state, capable of determining the public goods, persistent public objectives and target levels, independently evaluating the private system processes and outcomes, and shaping the critical factors of the processes in a permanent learning and adaptation attitude, always prepared to quickly and massively intervene in structural and institutional terms. Obviously, this will be infeasible after four decades of neoliberal dismantling of a proactive state. The state would have to considerably qualify and adapt its structures for appropriately complex and effective action.[25]

It is hardly surprising that the policy implications of CE reveal the relevance of an independent socio-economic political evaluation of system dynamics and results. With this, it resonates a conception of policy that was developed in the 1920s by American pragmatism and instrumentalism (Dewey 1925 [1931]), and further developed theoretically and implemented practically by institutionalism in the 1920s and 1930s as a negotiated economy (Commons 1934). As such, it needs to be

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[25] For example, see Faggini and Parziale (2016), on coevolutionary federal state structures.

accompanied, qualified and developed by a broad process of social inquiry, as such socio-economic valuations do not fall from the sky, nor are they a ‘natural’ result of a value-free ‘market’ mechanism; they need to be made societally (including distributionally) transparent, reasonable and problem-solving (Ramstad 1991). This conception was rudimentarily applied during the New Deal in the USA in the 1930s, and later operationalized by Institutionalists into the instrumental value principle (Tool 1979 [2001]). Complexity policy converges with the pragmatist approach of better problem-solving through continuing inquiry, learning, experimentation, adaptation and broad democratic participation.[26] It thus not only provides massive new causal knowledge, but also makes obvious the inevitable social evaluations required for institutional reform – with a clear view that intervention, learning, adaptation and experimentation in policy may never end.

REFERENCES

Acemoglu, Daron, Vasco Carvalho, Asuman Ozdaglar and Alireza Tahbaz-Salehi (2012), ‘The network origins of aggregate fluctuations’, *Econometrica*, 80(5), 1977–2016.

Acemoglu, Daron, Asuman Ozdaglar and Alireza Tahbaz-Salehi (2015), ‘Networks, shocks, and systemic risk’, prepared for *The Oxford Handbook on the Economics of Networks*, 2016, cited here as: Columbia Business School Research Paper, available at: hq.ssrn.com/Journals/RedirectClick.cfm?url=http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2560015&partid=356430&did=244421&eid=332463; retrieved 20 January 2017.

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

Arthur, Brian (1989), ‘Competing technologies, increasing returns, and lock-in by historical events’, *Economic Journal*, 99, 116–131.

Arthur, Brian (2013), ‘Complexity economics: a different framework for economic thought’, SFI Working Paper 2013-04-012, available at: http://tuvalu.santafe.edu/~wbarthur/Papers/Comp.Econ.SFI.pdf; retrieved 20 January 2017.

Arthur, Brian (2015), *Complexity and the Economy*, Oxford: Oxford University Press.

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

Ashby, Ross (1956), *An Introduction to Cybernetics*, London: Chapman & Hall.

Aspara, Jaakko, Kalle Pajunen, Henrikki Tikkanen and Risto Tainio (2014), ‘Explaining corporate short-termism: self-reinforcing processes and biases among investors, the media and corporate managers’, *Socio-Economic Review*, 12(4), 667–693.

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

[26] The Institutionalist theory of participatory democracy has been further developed in Scholz-Waeckerle (2016).

Bak, Per and Kurt Chao Tang (1987), 'Self-organized criticality: an explanation of 1/*f* noise', *Physical Review Letters*, 59(4), 381–384.

Barabási, Albert-László and Réka Albert (1999), 'Emergence of scaling in random networks', *Science*, 284(5439), 509–512.

Battiston, Stefano, Guido Caldarelli, Robert May, Tarik Roukny and Joseph Stiglitz (2015), *The Price of Complexity in Financial Networks*, available at: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2594028; retrieved 20 January 2017.

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

Beinhocker, Eric (2012), 'New economics, policy and politics', in T. Dolphin and D. Nash (eds), pp. 134–146.

Berger, Sebastian and Wolfram Elsner (2007), 'European contributions to evolutionary institutional economics: the cases of "cumulative circular causation" (CCC) and "open systems approach" (OSA)', *Journal of Economic Issues*, 41(2), 529–537.

Berninghaus, Siegfried, Werner Gueth and Stephan Schosser (2013), 'Reciprocity in locating contributions: experiments on the neighborhood public good game', *games*, 4(2), 144–162.

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

Binmore, Ken (2011), *Natural Justice*, Oxford and New York: Oxford University Press.

Bloch, Harr and Stan Metcalfe (2011), 'Complexity in the theory of the developing firm', in C. Antonelli (ed.), *Handbook on the Economic Complexity of Technological Change*, Cheltenham, UK, Northampton, MA: Edward Elgar Publishing, pp. 81–104.

Bush, Paul (1987), 'The theory of institutional change', *Journal of Economic Issues*, 21(3), 1075–1116.

Bush, Paul (1999), 'Recognized interdependence', in P.A. O'Hara (ed.), *Encyclopedia of Political Economy*, Vol. 2, London and New York: Routledge, pp. 963–964.

Calvert, Randall (1995), 'The rational choice theory of institutions: implications for design', in D. Weimer (ed.), *Institutional Design*, Heidelberg: Springer, pp. 63–94.

Charness, Gary and Chun-Lei Yang (2014), 'Starting small towards voluntary formation of efficient large groups in public goods provision', *Journal of Economic Behavior and Organization*, 102, 119–132.

Chertow, Marian and John Ehrenfeld (2012), 'Organizing self-organizing systems', *Journal of Industrial Ecology*, 16(1), 13–27.

Colander, David and Roland Kupers (2014), *Complexity and the Art of Public Policy: Solving Society's Problems from the Bottom Up*, Princeton, NJ: Princeton University Press.

Colander, David, Richard Holt and Barkley Rosser (2011), 'The complexity era in economics', *Review of Political Economy*, 23(3), 357–369.

Commons, John (1934), *Institutional Economics: Its Place in Political Economy*, New York: Macmillan (reprinted New Brunswick: Transaction, 1990).

Cozzo, E., G. Ferraz de Arruda, F.A. Rodrigues and Y. Moreno (2016), 'Multilayer networks: metrics and spectral properties', in F. Schweitzer and A. Garas (eds), *Interconnected Networks*, Heidelberg: Springer, available at: https://arxiv.org/pdf/1504.05567.pdf; retrieved 16 March 2017.

Dai, Shuanping and Wolfram Elsner (2015), *Declining Trust in Growing China*, available at: https://ideas.repec.org/p/zbw/udedao/1012015.html; retrieved 31 January 2017.

David, Paul (1985), 'Clio and the economics of QWERTY', *American Economic Review*, 75(2), 332–337.

Davidson, Paul (1982/1983), 'Rational expectations: a fallacious foundation for studying crucial decision-making processes', *Journal of Post-Keynesian Economics*, V(2), 182–198.

Dewey, John (1925 [1931]), 'The development of American pragmatism', in: Idem, *Philosophy and Civilization*, New York: Capricorn Books, pp. 13–35.
Dolphin, Tony and David Nash (eds) (2012), *Complex New World: Translating New Economic Thinking into Public Policy*, London: Institute for Public Policy Research.
Dopfer, Kurt (2011), 'Economics in a cultural key: complexity and evolution revisited', in J.B. Davis and D.W. Hands (eds), *Elgar Companion to Recent Economic Methodology*, Cheltenham, UK and Northampton, MA: Edward Elgar Publishing, pp. 319–340.
Durlauf, Steven (1997), 'What should policymakers know about economic complexity?', available at: https://ideas.repec.org/p/wop/safiwp/97-10-080.html; retrieved 20 January 2017.
Durlauf, Steven (2012), 'Complexity, economics, and public policy', *Politics, Philosophy & Economics*, 11(1), 45–75.
Elsner, Wolfram (2001), 'Interactive economic policy: toward a cooperative policy approach for a negotiated economy', *Journal of Economic Issues*, 35(1), 61–83.
Elsner, Wolfram (2005), 'Real-world economics today: the new complexity, co-ordination, and policy', *Review of Social Economy*, 63(1), 19–53.
Elsner, Wolfram (2012), '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), 1–43.
Elsner, Wolfram and Torsten Heinrich (2009), 'A simple theory of "meso": on the co-evolution of institutions and platform size', *Journal of Socio-Economics*, 38, 843–858.
Elsner, Wolfram and Henning Schwardt (2014), 'Trust and arena size: expectations, institutions, general trust, and critical population and group sizes', *Journal of Institutional Economics*, 10(1), 107–134.
Elsner, Wolfram, Torsten Heinrich and Henning Schwardt (2015), *Microeconomics of Complex Economies: Evolutionary, Institutional and Complexity Perspectives*, San Diego, Oxford and Amsterdam: Elsevier/Academic Press.
Epstein, Joshua and Robert Axtell (1996), *Growing Artificial Societies: Social Science from the Bottom Up*, Cambridge, MA: MIT Press.
Faggini, Marisa and Anna Parziale (2016), 'A new perspective for fiscal federalism: the NK model', *Journal of Economic Issues*, 50(4), 1069–1104.
Fontana, Magda (2010), 'Can neoclassical economics handle complexity? The fallacy of the oil spot dynamic', *Journal of Economic Behavior & Organization*, 76(3), 584–596.
Fontana, Magda (2012), 'Policy in complex social systems', in P. Heritier and P. Silvestri (eds), *Good Government, Governance, Human Complexity*, Florence: L.S. Olschki, pp. 221–233.
Fontana, Magda and Pietro Terna (2015), 'From agent-based models to network analysis (and return), the policy-making perspective', Università Degli Studi di Torino, Working Paper 07/15.
Foster, John (2005), 'From simplistic to complex systems in economics', *Cambridge Journal of Economics*, 29(6), 873–892.
Foster, John (2006), 'Why is economics not a complex systems science?', *Journal of Economic Issues*, 40(4), 1069–1091.
Gallegati, Mauro, Alan Kirman and Antonio Palestrini (2007), 'Implications of scaling laws for policy-makers', in M. Salzano and D. Colander (eds) (2007), pp. 291–302.
Garbellini, Nadia (2016), 'Small fiscal multipliers do not justify austerity: a macroeconomic accounting analysis of public debt-to-GDP dynamics', *Journal of Economic Issues*, 50(4), 1027–1044.
Garnsey, E. and J. McGlade (2006), *Complexity and Co-Evolution: Continuity and Change in Socio-Economic Systems*, Cheltenham, UK and Northampton, MA: Edward Elgar Publishing.

Geyer, Robert and Paul Cairney (eds) (2015), *Handbook on Complexity and Public Policy*, Cheltenham, UK and Northampton, MA: Edward Elgar Publishing.
Geyer, Robert and Samir Rihani (2010), *Complexity and Public Policy: A New Approach to Twenty-first Century Politics, Policy and Society*, London and New York: Routledge.
Gilles, Robert, Emiliya Lazarova and Pieter Ruys (2015), 'Stability in a network economy: the role of institutions', *Journal of Economic Behavior and Organization*, 119, 375–399.
Glaeser, Edward, David Laibson and Bruce Sacerdote (2002), 'An economic approach to social capital', *Economic Journal*, 112(483), F437–F458.
Hallsworth, Michael (2012), 'How complexity economics can improve government: rethinking policy actors, institutions, and structures', in Tony Dolphin and David Nash (eds) (2012), pp. 39–49.
Hargreaves-Heap, Shaun (1989), *Rationality in Economics*, New York: Blackwell.
Harper, David and Paul Lewis (2012), 'New perspectives on emergence in economics', *Journal of Economic Behavior and Organization*, 82(2–3), 329–337.
Hayden, Gregory (2006), *Policymaking for a Good Society: The Social Fabric Matrix Approach to Policy Analysis and Program Evaluation*, New York: Springer.
Heinrich, Torsten (2013), *Technological Change and Network Effects in Growth Regimes: Exploring the Microfoundations of Economic Growth*, London and New York: Routledge.
Heinrich, Torsten (2016), 'A discontinuity model of technological change: catastrophe theory and network structure', *Computational Economics*, available at: http://link.springer.com/article/10.1007/s10614-016-9609-9; retrieved 23 March 2017.
Heinrich, Torsten and Henning Schwardt (2013), 'Institutional inertia and institutional change in an expanding normal-form game', *games*, 4, 398–425.
Helbing, Dirk (2013), 'Globally networked risks and how to respond', *Nature*, 497, 51–59.
Hodgson, Geoffrey (2002), 'Reconstitutive downward causation: social structure and the development of individual agency', in E. Fullbrook (ed.), *Intersubjectivity in Economics: Agents and Structures*, London and New York: Routledge, pp. 159–180.
Holland, John (2006), 'Studying complex adaptive systems', *Journal of Systems Science and Complexity*, 19(1), 1–8.
Houser, Daniel, D. Levy, K. Padgitt, S. Peart and E. Xiao (2014), 'Raising the price of talk: an experimental analysis of transparent leadership', *Journal of Economic Behavior and Organization*, 105, 208–218.
Hu, Hai-hua, Jun Lin and Wen-tian Cui (2015), 'Intervention strategies and the diffusion of collective behavior', *Journal of Artificial Societies and Social Simulation*, 18(3), 1–14.
Jackson, Matthew and Yves Zenou (2015), 'Games on networks', in P. Young and S. Zamir (eds), *Handbook of Game Theory*, Vol. 4, Amsterdam: Elsevier, pp. 91–157.
Jackson, Matthew, Brian Rogers and Yves Zenou (2017), 'The economic consequences of social network structure', available at: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2467812; retrieved 24 January 2017.
Jennings, Frederic (2005), 'How efficiency/equity trade-offs resolve through horizon effects', *Journal of Economic Issues*, 39(2), 365–373.
Jun, Tackseung and Rajiv Sethi (2007), 'Neighborhood structure and the evolution of cooperation', *Journal of Evolutionary Economics*, 17, 623–646.
Kao, Albert and Lain Couzin (2014), 'Decision accuracy in complex environments is often maximized by small group sizes', *Proceedings of the Royal Society B*, 281(1784), available at: http://classic.rspb.royalsocietypublishing.org/content/281/1784/20133305.short; retrieved 24 January 2017.
Kauffman, Stuart (1993), *The Origins of Order: Self-Organization and Selection in Evolution*, Oxford: Oxford University Press.
Kendall, G., X. Yao and S. Chong (eds) (2007), *The Iterated Prisoner's Dilemma: 20 Years On*, Singapore: World Scientific.

Kesternich, Martin, Andreas Lange and Bodo Sturm (2014), 'The impact of burden sharing rules on the voluntary provision of public goods', *Journal of Economic Behavior and Organization*, 105, 107–123.
Kirman, Alan (1998a), 'The economy as an evolving network', *Journal of Evolutionary Economics*, 7, 339–353.
Kirman, Alan (1998b), 'Self-organization and evolution in economics', in F. Schweitzer and G. Silverberg (eds), *Evolution and Self-Organization in Economics*, Berlin: Ducker & Humblot, pp. 13–45.
Kirman, Alan (2011), *Complex Economics: Individual and Collective Rationality*, London and New York: Routledge.
Kirman, Alan (2016), 'Complexity and economic policy: a paradigm shift or a change in perspective?', *Journal of Economic Literature*, 54(2), 534–572.
Krockow, Eva, Briony Pulford and Andrew Colman (2015), 'Competitive centipede games: zero-end payoffs and payoff inequality deter reciprocal cooperation', *games*, 6(3), 262–272.
Lewin, Peter (2014), 'Policy design and execution in a complex world: can we learn from the financial crisis?', University of Texas Dallas, available at: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2473258; retrieved 24 January 2017.
Lindgren, Kristian (1997), 'Evolutionary dynamics in game-theoretic models', in B. Arthur, S. Durlauf and D. Lane (eds), *The Economy as an Evolving Complex System II*, Reading, MA: Addison-Wesley, pp. 337–367.
Lloyd, Seth (2001), 'Measures of complexity: a non-exhaustive list', *IEEE Control Systems Magazine*, August, pp. 7–8.
Loasby, Brian (2012), 'Building systems', *Journal of Evolutionary Economics*, 22(4), 833–846.
López-Pérez, Raúl, Ágnes Pintér and Hubert Kiss (2015), 'Does payoff equity facilitate coordination? A test of Schelling's conjecture', *Journal of Economic Behavior and Organization*, 117, 209–222.
Lux, Thomas and Michele Marchesi (1999), 'Scaling and criticality in a stochastic multi-agent model of a financial market', *Nature*, 397, 498–500.
Mandelbrot, Benoit (1997), *Fractals and Scaling in Finance: Discontinuity, Concentration, Risk*, Heidelberg: Springer.
Mandelbrot, Benoit and Richard L. Hudson (2006), *The Misbehavior of Markets: A Fractal View of Financial Turbulence*, New York: Basic Books.
Markey-Towler, Brendan (2016), *Principles of Forecasting in Complex Economic Systems*, available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2907197; retrieved 23 March 2017.
Markose, Sheri M. (2016), 'Complex type-4 structure changing dynamics of digital agents: Nash equilibria of a game with arms race in innovations', University of Essex, available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2900533; retrieved 2 February 2017.
McCain, Roger (2009), *Game Theory and Public Policy*, Cheltenham, UK and Northampton, MA: Edward Elgar Publishing.
Miller, John and Scott Page (2007), *Complex Adaptive Systems: An Introduction to Computational Models of Social Life*, Princeton, NJ: Princeton University Press.
Mirowski, Philip (2013), 'Market complexity and the nature of crises in financial markets', in L. Taylor, A. Rezai and T. Michl (eds), *Social Fairness and Economics*, London and New York: Routledge, pp. 374–393.
Mitchell, Melanie (2009), *Complexity: A Guide*, Oxford and New York: Oxford University Press.
Morçöl, Göktu (2012), *A Complexity Theory for Public Policy*, London and New York: Routledge.

Nishi, Akihiro, Hirokazu Shirado, David Rand and Nicholas Christakis (2015), 'Inequality and visibility of wealth in experimental social networks', *Nature*, DOI: 10.1038/nature15392; retrieved 24 January 2017.
Nowak, Martin (2006), *Evolutionary Dynamics: Exploring the Equations of Life*, Cambridge, MA: Harvard University Press.
O'Donnell, Rod (2014), 'A critique of the ergodic/nonergodic approach to uncertainty', *Journal of Post-Keynesian Economics*, 37(2), 187–209.
OECD (2009), *Applications of Complexity Science for Public Policy: New Tools for Finding Unanticipated Consequences and Unrealized Opportunities*, Paris: OECD.
Ormerod, Paul (2012), 'Networks and the need for a new approach to policymaking', in Tony Dolphin and David Nash (eds) (2012), pp. 28–38.
Papachristos, George (2017), 'Diversity in technology competition: the link between platforms and sociotechnical transitions', *Renewable and Sustainable Energy Reviews*, 73, 291–306, available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2915736; retrieved 21 March 2017.
Price, Jim, Philip Haynes, Mary Darking, Julia Stroud, Christopher Warren-Adamson and Carla Ricaurte (2015), 'The policymaker's complexity toolkit', in Robert Geyer and Paul Cairney (eds) (2015), pp. 92–110.
Prigogine, Ilya and Grégoire Nicolis (1967), 'On symmetry-breaking instabilities in dissipative systems', *Journal of Chemical Physics*, 46, 3542–3550.
Ramstad, Yngve (1991), 'From desideratum to historical achievement: John R. Commons's reasonable value and the "negotiated economy" of Denmark', *Journal of Economic Issues*, 25(2), 431–439.
Richards, Sue (2012), 'Regional policy and complexity: towards effective decentralisation', in Tony Dolphin and David Nash (eds) (2012), pp. 121–133.
Room, Graham (2011), *Complexity, Institutions and Public Policy: Agile Decision-Making in a Turbulent World*, Cheltenham, UK and Northampton, MA: Edward Elgar Publishing.
Rosser, J. Barkley (2015/2016), 'Reconsidering ergodicity and fundamental uncertainty', *Journal of Post-Keynesian Economics*, 38(3), 331–354, available at: http://www.tandfonline.com/doi/abs/10.1080/01603477.2015.1070271; retrieved 18 January 2017.
Rycroft, Robert W. and Don E. Kash (1999), *The Complexity Challenge: Technological Innovation for the 21st Century*, London and New York: Pinter.
Salzano, M. and D. Colander (eds) (2007), *Complexity Hints for Economic Policy*, Milan: Springer.
Schelling, Thomas (1971), 'Dynamic models of segregation', *Journal of Mathematical Sociology*, 1, 143–186.
Scholz-Waeckerle, Manuel (2016), 'Democracy evolving: a diversity of institutional contradictions transforming political economy', *Journal of Economic Issues*, 50(4), 1003–1026.
Schotter, Andrew (1981), *The Economic Theory of Social Institutions*, Cambridge, UK: Cambridge University Press.
Sen, Amartya (1967), 'Isolation, assurance and the social rate of discount', *Quarterly Journal of Economics*, 81(1), 112–124.
Sen, Amartya K. (1977), 'Rational fools: a critique of the behavioral foundations of economic theory', *Philosophy and Public Affairs*, 6(4), 317–344.
Shackle, George L.S. (1949), *Expectations in Economics*, Concord, NH: Gibson Press.
Simon, Herbert (1962), 'The architecture of complexity', *Proceedings of the American Philosophical Society*, 106, 467–482.
Solari, Stefano and Francesca Gambarotto (2014), 'Territorial rooting as an element of well-being', *Review of Social Economy*, 72(4), 504–522.
Taleb, Nassim (2007), *The Black Swan: The Impact of the Highly Improbable*, London and New York: Penguin Books.

Tang, Yinan and Ping Chen (2015), 'Transition probability, dynamic regimes, and the critical point of financial crisis', *Physica A*, 430(C), 11–20.
Thornton, Tim (2016), 'The 'Complexity Revolution' seen from a historical and heterodox perspective', in J. Courvisanos, J. Doughney and A. Millmow (eds), *Reclaiming Pluralism in Economics*, London and New York: Routledge, pp. 238–250.
Tool, Marc R. (1979 [2001]), *The Discretionary Economy: A Normative Theory of Political Economy*, Santa Monica, CA: Goodyear Publishers.
Valentinov, Vladislav and Lioudmila Chatalova (2016), 'Institutional economics and social dilemmas: a systems theory perspective', *Systems Research and Behavioral Science*, 33(1), 138–149, DOI: 10.1002/sres.2327; accessed 31 January 2017.
Van den Berg, Hendrik (2016), 'Mainstream economics' flight from complexity', *Forum for Social Economics*, DOI: 10.1080/07360932.2015.1028085; retrieved 24 January 2017.
Veblen, Thorstein B. (1898), 'Why is economics not an evolutionary science?', *Quarterly Journal of Economics*, 12(4), 373–397.
Veblen, Thorstein B. (1899), *The Theory of the Leisure Class: An Economic Study of Institutions*, New York: Macmillan.
Vega-Redondo, Fernando (2013), 'Network organizations', *Journal of Complex Networks*, 1, 72–82.
Velupillai, Vela (ed.) (2005), *Computability, Complexity and Constructivity in Economic Analysis*, Hoboken, NJ: Wiley–Blackwell.
Velupillai, Vela (2007), 'The impossibility of an effective theory of policy in a complex economy', in M. Salzano and D. Colander (eds) (2007), pp. 273–290.
Ver Eecke, Wilfried (2008), *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 and Heidelberg: Springer.
Waldrop, Mitchell (1992), *Complexity: The Emerging Science at the Edge of Order and Chaos*, New York and London: Simon & Schuster.
Watts, Duncan (1999), *Small Worlds: The Dynamics of Networks Between Order and Randomness*, Princeton, NJ and London: Princeton University Press.
Watts, Duncan and Steven Strogatz (1998), 'Collective dynamics of "small-world" networks', *Nature*, 393(6684), 440–442.
Weaver, Warren (1948), 'Science and complexity', *American Scientist*, 36(4), 536–544.
Wilson, David (2014), 'Two meanings of complex adaptive systems', Mimeo, Binghamton University, New York (published in D.S. Wilson and A. Kirman (eds), *Complexity and Evolution: Towards a New Synthesis for Economics*, Cambridge, MA and London: MIT Press, pp. 31–46).
Wilson, David and John Gowdy (2013), 'Evolution as a general theoretical framework for economics and public policy', *Journal of Economic Behavior and Organization*, 90S, S3–S10.
Witt, Ulrich (2003), 'Economic policy making in evolutionary perspective', *Journal of Evolutionary Economics*, 13(1), 77–94.