Complexity: Theory and Computational Models - Extensive Reading List

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Abstract

Here we provide you with some additional reading suggestions in case you want to dig deeper into the topics. The reading suggestions are of course subjective, but we tried to cover different and rivalry perspectives.

1 Meta-theoretical foundations and history

1.1 Core readings

These rather concise articles give you a pretty good idea about the meta-theoretical issues involved:

Gräbner (2017) is a very short intro to the concept of systems and how it relates to economics, in particular evolutionary economics. Despite this focus it also entails some basic exposition of systemism (published paper, restricted; accepted manuscript, freely available).

Arthur (2010) is a nice historical overview over the roots of complexity economics from one of its most prominent founding fathers (Jstor link, restricted).

Gräbner (2018a) introduces the basic philosophical terminology you need to talk seriously about models and their relation to reality. It focuses on computational models, but most concepts are more general. Many references are given, and particular attention is given to model verification and model validation, i.e. the establishment of claims about the empirical adequacy of models (open access publication link, I recommend the PDF version).

Finally, Gräbner (2018b) discusses the relationship between complexity and pluralism, and justifies the latter with reference to the former (accepted manuscript, freely available).

1.2 Additional reading

The following articles go deeper into the subject matter or represent original contributions that should be of interest to all who want to study the ontological, epistemological, and methodological foundations of complexity economics in more detail.

Beinhocker (2006) is an very well-written popular science book on the foundation of complexity and evolutionary economics. It contains a large number of interesting historical notes.

Mitchell (2009) is another very nice popular science book. It is not focused on complexity *economics* but on the complexity approach in general. Thus, it is a nice read, thought-provoking, and with a lot of great references.

Blume and Durlauf (2005) is the introduction to a proceeding book of the complexity economics conference at SFI in 2005. It proves that not all see complexity economics as a rival to orthodox economics. For other critical (but, we believe, misleading) remarks from the same author see Durlauf (2005).

Elsner, Heinrich, and Schwardt (2015) is a microeconomics textbook, written from a complexity perspective. It illustrates the relation of complexity economics to other research programs and has a very concise but excellent introduction to game theory, dynamical systems theory and agent-based modeling.

A classical text on how complex systems emerge is by Simon (1962). His argument is very relevant and applicable to economic systems.

One of the classical texts on what complexity is about is by Weaver (1948). Here he makes his famous distinction between problems of *simplicity*, *dis-organized complexity* and *organized complexity*.

The philosophical framework of systemism comes from Mario Bunge. A general introduction can be found in Bunge (2000). Gräbner and Kapeller (2017) is a more in-depth treatment of systemism as a philosophical framework for many different schools of thought in economics. Why mechanisms are an essential part of every system and must be considered for successful explanation is argued concisely in Bunge (1997), and applied to economics in Gräbner (2017).

1.2.1 Some readings on ontology

An influential stream of literature is the 'Cambridge School of Ontology', and its 'social ontology' or 'critical realism'. The basic reference is Lawson (1997).

Another influential (but rival) approach is 'evolutionary realism', as advocated by Dopfer and Potts (2008). See Dopfer and Potts (2010) for a critical exchange between the two approaches.

Hodgson (2006) critically discusses both approaches from an institutionalist and marxist perspective.

Indirectly related to ontology is the question of how to define things. The discussion about the essential properties of objects clearly refers to this area. Despite its age Robinson (1962) is still *the* work on

definition. But make sure to read the great intro to *essentialism* in chapter 2 of Hodgson (2015). He takes up several arguments of Robinson (1962) and accommodates them within the actual discourse.

1.2.2 Some readings on epistemology

An excellent epistemological critique of neoclassical economics, based on the works of Popper, Albert and Rothschild is Kapeller (2013).

There are a number of interpretations of economic models and how they create knowledge. Actually, every economist should know about at least the following:

Robert Sugden (2000) sees models as descriptions of 'credible worlds', from which we can draw conclusions about reality. A very influential interpretation. Uskali Mäki (2009a) considers models as ways to isolate aspects of reality. Thus, his framework is called 'Models as Isolations and Surrogate Systems'. I think this framework is useful, in particular in combination with his 'Functional Decomposition Approach' (Mäki, 2009b). Still, it is not without flaws, as described in Grüne-Yanoff (2011). Another influential strand sees models more as fables Rubinstein (2012)[1] or narratives (Shiller, 2017). For numerous high-level approaches from philosophers of science you might consult the *Handbook of Model-Based Science* (Magnani & Bertolotti, 2017), in particular the contribution of Frigg and Nguyen (2017).

The recent book by Dani Rodrik (2016) critically assesses how economists use models. Its not really a professional text in economic epistemology, but its a very well-written and instructive book. Make sure to have a look at the excellent and critical review by Rubinstein (2017). Also, there is a current symposium in the *Journal of Economic Methodology* on the book, including three contributions (here, here, and here) and a response of Rodrik (here).

Studies in economic methodology and epistemology are not necessarily critical. Many philosophers see their job in *explaining* how people create knowledge with 'simple' models, rather than *assessing* whether this strategy is good. Grüne-Yanoff (2011) and Ylikoski and Aydinonat (2014) provide good examples for this type of literature. For you as a consumer of methodological literature it is important to keep these different orientations within the literature in mind.

If you are interested in the different ways how more applied models can be related to reality, you may have a look at Gräbner (2018a)[2], which focuses on the verification-validation distinction, and is written for a computer science and simulation studies audience.

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[1] This book is published by Open Books and thus freely available here.

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2 Introduction to network theory

2.1 Textbooks

A nice (and free) introduction for beginners, which also covers game theory, is given by Easley and Kleinberg (2010). It is a good start, but does not go really deep into the material.

An already classical textbook is written by the 'pope of network science' Mark Newman (M. Newman, 2010). Its excellent, but keep in mind it is written from a physicists point of view and most examples are from the natural sciences. Newman also wrote an extensive article introducing fundamental concepts of network theory (M. E. J. Newman, 2003), which is a good (and free) read.

van Steen (2010) is an excellent (and free) book on the mathematical foundations of graph theory. I learned a lot from this book and I can really recommend it.

Another well-known source for networks in economics is Goyal (2009) but I would judge it a bit too theoretical and sympathetic to standard economics.

2.2 Example papers

There are far too many good papers that apply network theory to economics, so the following collection is highly subjective and incomplete. Some examples include papers on the product space (Hidalgo, Klinger, Barabási, & Hausmann, 2007), inter-banking networks and stress testing (Cont & Minca, 2016), technological change (Heinrich, 2013), and industrial organization Uzzi, Amaral, and Reed-Tsochas (2007).

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3 Introduction to dynamical systems

Concise introductions on the use of dynamical systems in economics are given by Foley (1998) and Kirman (1997).

An excellent textbook on the analytical treatment of dynamical systems is Gandolfo (2009). It starts from the very start but moves on relatively quickly. Lorenz (1993) is, despite its age, still highly recommendable and moves to more advance techniques rather quickly.

A good alternative for newcomers is Feldman (2012), which is dedicated to beginners and not directly focused on economics, but captures many applications in the complexity sciences.

Applications to economics

Some of the earlier models of business cycles made use of dynamical systems to generate circular dynamics, e.g. Samuelson (1939) and Goodwin (1967), though many of the newer non-equilibrium models tend to use an agent-based approach instead. The neoclassical Solow-Swan growth model (Solow, 1956) is also a dynamical system, though the dynamics are not cyclic and almost trivial. For a discussion of some neoclasscial models from a dynamical systems perspective, see the examples in Gandolfo (2009).

Non-equilibrium macro-models often resort to dynamical systems as dynamical systems are not limited to near-equilibrium patterns. See e.g. Lorenz (1987), Keen (1995), Grasselli and Costa Lima (2012) and Stockhammer and Michell (2014).

Note that as exemplified by Lorenz (1987) and Keen (1995), even log-dimensional dynamical systems quickly lead to deterministic chaos, which, in turn, has epistemological implications.

Applications outside the domain of growth theory and macroeconomics include strategy choice and technological change (Arthur, Ermoliev, & Kaniovski, 1987), where systems frequently show discontinuities and bifurcations (Dou & Ghose, 2006; Heinrich, 2016; Rosser, 2000).

Replicator dynamics is a specific case of dynamical systems - applied to state variables that represent population shares. Besides obvious uses in evolutionary biology, they are well-suited to tackle models of competition, market shares, and strategy choice in economics. For an introduction, see e.g. the second chapter in Nowak (2006). For some examples and an extensive overview of the literature, see Safarzynska and van den Bergh (2011).

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4 Empirics and heavy-tailed distributions

Good introductions to power law distributions and their relevance for economics are offered by Farmer and Geanakoplos (2008) (freely available as SFI working paper) and Newman (2005) (freely available on arXiv). For a broader introduction to scaling laws in connection to self-organization, see Per (1996).

A slightly more technical introduction to the more general L'evy alpha-stable distribution can be found in

Frank (2009), which also explains the connections to the maximum entropy approach and the central limit theorem. For a still more technical but comprehensive analysis of the L'evy alpha-stable distribution, see Nolan (2019).

The standard approach to identifying and fitting power law tails is explained by Clauset, Shalizi, and Newman (2009) (freely available in a different and a bit more extensive version on arXiv). Clauset et al. (2009) also offer a very good introduction to empirical approaches to heavy tailed distributions. They are critical of ubiquitous studies that claim to identify power laws in spite of flawed methodology. However, the methodology they suggest is known to be conservative, to often err on the side of caution and to lead to inconclusive results even for definitive power law data. Alternative methodologies have been suggested (Bouchaud & Potters, 2003; Farmer & Geanakoplos, 2008; Trapani, 2016).

Mitzenmacher (2003), Newman (2003), and Lux (2006) provide nice surveys of generative mechanisms that produce power laws and discusses the relation between power laws and log-normal distributions.

A critical note on the link between generative mechanisms and observed power law distributions is given by Shalizi (2014). His argument can be considered as a plea for mechanism-based explanations of power laws (compare the epistemological section above).

Gabaix (2016) gives a nice overview over the presence and role of power laws in economics from a more mainstream perspective.

As examples for applied paper you may want to have a look at Axtell (2001) who shows that firm size distributions in the USA are power law distributed, or Heinrich and Dai (2016) who are concerned with firm sizes in various Chinese provinces.

A largely non-technical overview over the role of heavy-tailed distribution in finance is given in Mandelbrot and Hudson (2004).

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5 Introduction to agent-based modeling

For accessible but formal and practical introductions to ABM, see Macal and North (2010) or Chapter 9 in Elsner, Heinrich, and Schwardt (2015). An introduction setting out more from the game theory side would be Isaac (2008). Conceptual introductions are provided by Borrill and Tesfatsion (2011), Epstein (2006), Delli Gatti, Gaffeo, Gallegati, Giulioni, and Palestrini (2008), and Pyka and Fagiolo (2005).

Of course, any programming language - general purpose or focussed on ABM - can be used for writing agent-based models. There are far too many programming languages and general programming (as opposed to ABS) introductions to the same for us to compile a comprehensive list. A general introduction to Python would, for example, be Downey, Elkner, and Meyers (2002), but taking an online course is probably better. A very prominent platform that is specifically dedicated to ABM is Netlogo. An excellent introduction to ABM with many examples in Netlogo is Railsback and Grimm (2019), which has a good companion website.

There is a very long history of agent-based models in economics and an even longer one in other fields. Some examples include models of spatial segregation (Schelling, 1971), of technological change (Nelson & Winter, 1974, 1982), of the emergence of cooperation (Axelrod, 1984), of economic growth (Dosi, Fagiolo, & Roventini, 2010; Saviotti & Pyka, 2013; Silverberg & Lehnert, 1993) or of financial stress testing (Poledna, Thurner, Farmer, & Geanakoplos, 2014; Tedeschi, Iori, & Gallegati, 2012). For a nice general assessment and overview on macroeconomic ABM see, for example, this introduction to a recent special issue (Dosi & Roventini, 2019) or this book chapter in the Handbook for Computational Economics.

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