Complexity: Theory and Computational Models - Extensive Reading List

Claudius Gräbner[1] and Torsten Heinrich[2]

[1]Johannes Kepler University
[2]University of Oxford

August 4-11 2017, Neudietendorf
Version 1.0. of October 25, 2017

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

Gräbner and Kapeller (2017) is a more in-depth treatment of systemism as a philosophical framework for many different schools of thought in economics.

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

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 proofs that not all see complexity economics as a rival to orthodox economics. For other critical (but, I 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 here. Why mechanisms are an essential part of every system and must be considered for successful explanation is argued concisely in Bunge (1997), and a applied to economics in Gräbner (2017b).

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 K. D. Potts and Jason (2008). See Dopfer and Potts (2010) for an argument 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 really like this framework, in particular in combination with his 'Functional Decomposition Approach' (Mäki, 2009b). I referred to both a lot during the lectures. Yet another influential strand sees models more as fables Rubinstein (2012)[1] or narratives (Shiller, 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).

Studies in economic methodology and epistemolgy 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 (2017a) (here), which focuses on the verification-validation distinction, and is written for a computer science and simulation studies audience.

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

References

Arthur, W. B. (2010). Complexity, the Santa Fe Approach, and Non-Equilibrium Economics. *History of Economic Ideas*.

Beinhocker, E. D. (2006). *The Origin of Wealth*. Harvard Business Press.

Blume, L. & Durlauf, S. N. (2005). Introduction. In *The economy as an evolving complex system iii*.

Bunge, M. (1997). Mechanisms and Explanation. *Philosophy of the Social Sciences*.

Dopfer, K. & Potts, J. (2010). Why evolutionary realism underpins evolutionary economic analysis and theory: A reply to Runde's critique. *Journal of Institutional Economics*.

Durlauf, S. N. (2005). Complexity and Empirical Economics. *The Economic Journal*.

Elsner, W., Heinrich, T., & Schwardt, H. (2015). *The Microeconomics of Complex Economies: Evolutionary, Institutional, Neoclassical, and Complexity Perspectives*. Elsevier/Academic Press.

Gräbner, C. (2017a). How to relate models to reality? An epistemological framework for the validation and verification of computational models. *ICAE Working Paper*, *63*.

Gräbner, C. (2017b). The Complementary Relationship Between Institutional and Complexity Economics: The Example of Deep Mechanismic Explanations. *Journal of Economic Issues*.

Gräbner, C. & Kapeller, J. (2017). The micro-macro link in heterodox economics. In *The routledge handbook of heterodox economics*.

Grüne Yanoff, T. (2011). Isolation Is Not Characteristic of Models. *International Studies in the Philosophy of Science*, *25*(2), 119–137.

Hodgson, G. M. (2006). *Economics in the Shadows of Darwin and Marx*. Edward Elgar.

Hodgson, G. M. (2015). *Conceptualizing Capitalism. Institutions, Evolution, Future*. University of Chicago Press.

Kapeller, J. (2013). 'Model-Platonism' in economics: on a classical epistemological critique. *Journal of Institutional Economics*.

Lawson, T. (1997). *Economics and Reality*. Routledge.

Mäki, U. (2009a). MISSing the World. Models as Isolations and Credible Surrogate Systems. *Erkenntnis*, *70*(1), 29–43.

Mäki, U. (2009b). Models and Truth: The Functional Decomposition Approach. In M. Suarez, M. Dorato, & M. Redei (Eds.), *Epsa epistemology and methodology of science* (pp. 177–187). Dordrecht: Springer Netherlands.

Mitchell, M. (2009). *Complexity. A Guided Tour*. Oxford University Press.

Potts, K. D. & Jason. (2008). *The General Theory of Economic Evolution*. Routledge.

Robinson, R. (1962). *Definition*. Clarendon Press.

Rodrik, D. (2016). *Economics Rules*. New York: Norton & Company.

Rubinstein, A. (2012). *Economic Fables*. Cambridge, UK: Open Book Publishers.

Rubinstein, A. (2017). Comments on Economic Models, Economics, and Economists: Remarks on <i>Economics Rules</i> by Dani Rodrik. *Journal of Economic Literature*, *55*(1), 162–72.

Shiller, R. J. (2017, April). Narrative Economics. *American Economic Review*, *107*(4), 967–1004.

Simon, H. A. (1962). The Architecture of Complexity. *Proceedings of the American Philosophical Society*.

Sugden, R. (2000). Credible worlds: the status of theoretical models in economics. *Journal of Economic Methodology*, *7*(1), 1–31.

Weaver, W. (1948). Science and Complexity. *American Scientist*.

Ylikoski, P. & Aydinonat, N. E. (2014). Understanding with theoretical models. *Journal of Economic Methodology*, *21*(1), 19–36.

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, and Hausmann (2007), inter-banking networks and stress testing Cont and Minca (2016), technological change (Heinrich, 2013), and industrial organization Uzzi, Amaral, and Reed-Tsochas (2007).

References

Cont, R. & Minca, A. (2016). Credit default swaps and systemic risk. *Annals of Operations Research*, *247*(2), 523–547.

Easley, D. & Kleinberg, J. (2010). *Networks, Crowds, and Markets*. Cambridge, UK et al.: Cambridge University Press.

Goyal, S. (2009). *Connections: An Introduction to the Economics of Networks*. Princeton: Princeton University Press.

Heinrich, T. (2013). *Technological Change and Network Effects in Growth Regimes*. London: Routledge.

Hidalgo, C. A., Klinger, B., Barabási, A.-L., & Hausmann, R. (2007). The Product Space Conditions the Development of Nations. *Science*, *317*(7), 482–487.

Newman, M. (2010). *Networks: An Introduction*. Oxford: Oxford University Press.

Newman, M. E. J. (2003, January). The Structure and Function of Complex Networks. *SIAM Review*, *45*(2), 167–256.

Uzzi, B., Amaral, L. A., & Reed-Tsochas, F. (2007). Small-world networks and management science research: a review. *European Management Review*, *4*(2), 77–91. doi:10.1057/palgrave.emr.1500078

van Steen, M. (2010). *Graph Theory and Complex Networks*. Amsterdam: Maarten van Steen.

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. The same could be done with modern neoclassical models, though this is not usually done and the resulting system is much more complicated. 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 macro economics include strategy choice and technological change Arthur, Ermoliev, and Kaniovski, 1987, where systems frequently show discontinuities and bifurcations (Rosser, 2000; Dou & Ghose, 2006; Heinrich, 2016).

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).

References

Arthur, W. B., Ermoliev, Y. M., & Kaniovski, Y. M. (1987). Path dependent processes and the emergence of macro-structure. *European Journal of Operational Research*, *30*, 294–303.

Dou, W. & Ghose, S. (2006). A dynamic nonlinear model of online retail competition using cusp catastrophe theory. *Journal of Business Research*, *59*(7), 838–848. doi:http://dx.doi.org/10.1016/j.jbusres.2006.02.003

Feldman, D. P. (2012). *Chaos and Fractals*. Oxford: Oxford University Press.

Foley, D. K. (1998). Introduction to 'barriers and bounds to rationality'. In D. K. Foley (Ed.), *Barriers and bounds to rationality: essays on economic complexity and dynamics in interactive systems, by albin, p.s., with an introduction by foley, d.k.* (pp. 3–72). Princeton, N.J.: Princeton University Press.

Gandolfo, G. (2009). *Economic Dynamics* (4th ed.). Springer.

Goodwin, R. M. (1967). A Growth Cycle. In C. H. Feinstein (Ed.), *Socialism, capitalism and economic growth*. Cambridge.

Grasselli, M. R. & Costa Lima, B. (2012). An analysis of the keen model for credit expansion, asset price bubbles and financial fragility. *Mathematics and Financial Economics*, *6*(3), 191–210. doi:10.1007/s11579-012-0071-8

Heinrich, T. (201616). A discontinuity model of technological change: catastrophe theory and network structure. *Computational Economics*. Retrieved from http://dx.doi.org/10.1007/s10614-016-9609-9

Keen, S. (1995). Finance and economic breakdown: modeling Minsky's "financial instability hypothesis". *Journal of Post Keynesian Economics*, *17*(4), 607–635.

Kirman, A. P. (1997). The economy as an interactive system. In W. B. Arthur, S. Durlauf, & D. Lane (Eds.), *The economy as an evolving complex system ii* (pp. 491–531). Reading, MA: Westview Press.

Lorenz, H.-W. (1987). Strange attractors in a multisector business cycle model. *Journal of Economic Behavior & Organization*, *8*(3), 397–411. doi:10.1016/0167-2681(87)90052-7

Lorenz, H.-W. (1993). *Nonlinear Dynamical Economics and Chaotic Motion* (2nd ed.). Berlin, Heidelberg: Springer.

Nowak, M. A. (2006). *Evolutionary dynamics: exploring the equations of life*. Cambridge, Mass.: Belknap Press of Harvard Univ. Press.

Rosser, J. B. (2000). *From catastrophe to chaos: a general theory of economic discontinuities: mathematics, microeconomics and finance*. New York: Springer.

Safarzynska, K. & van den Bergh, J. (2011). Beyond replicator dynamics: Innovation – selection dynamics and optimal diversity. *Journal of Economic Behavior and Organization*, *78*(3), 229–245.

Samuelson, P. A. (1939). Interactions between the multiplier analysis and the principle of acceleration. *The Review of Economics and Statistics*, *21*(2), 75–78.
Solow, R. M. (1956). A Contribution to the Theory of Economic Growth. *The Quarterly Journal of Economics*, *70*(1), 65–94.
Stockhammer, E. & Michell, J. (2014). Pseudo-goodwin cycles in a minsky model. Post Keynesian Study Group Working Paper No 1405, Available online: http://www.postkeynesian.net/downloads/wpaper/PKWP1405.pdf.

4 Empirics and heavy-tailed distributions

A great introduction and the standard receipt for identifying power laws is given by Clauset, Shalizi, and Newman (2009), which is freely available in a different and a bit more extensive version on arXiv).

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).

References

Axtell, R. L. (2001, September). Zipf Distribution of U.S. Firm Sizes. *Science*, *293*, 1818–1820.
Clauset, A., Shalizi, C. R., & Newman, M. E. J. (2009). Power-Law Distributions in Empirical Data. *SIAM Review*, *51*(4), 661–703.
Gabaix, X. (2016). Power Laws in Economics: An Introduction. *Journal of Economic Perspectives*, *30*(1), 185–206.
Heinrich, T. & Dai, S. (2016). Diversity of firm sizes, complexity, and industry structure in the Chinese economy. *Structural Change and Economic Dynamics*, *37*, 90–106.
Lux, T. (2006). *Financial power laws: empirical evidence, models, and mechanism* (Economics working paper / Christian-Albrechts-Universität Kiel, Department of Economics No. 2006,12). http://hdl.handle.net/10419/3923. Institut für Volkswirtschaftslehre, Kiel.
Mandelbrot, B. B. & Hudson, R. L. (2004). *The (mis)behavior of markets: A fractal view of risk, ruin, and reward*. New York, NY: Basic Books.
Mitzenmacher, M. (2003). A brief history of generative models for power law and lognormal distributions. *Internet Mathematics*, *1*(2), 226–251.
Newman, M. E. J. (2003). The structure and function of complex networks. *SIAM Review*, *45*(2), 167–256. doi:10.1137/S003614450342480
Shalizi, C. R. (2014). Power law distributions, 1/f noise, long-memory time series. Working Paper, available online: http://bactra.org/notebooks/power-laws.html.

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).

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 and Winter (1974, 1982), of the emergence of cooperation Axelrod (1984), of economic growth Silverberg and Lehnert, 1993; Dosi, Fagiolo, and Roventini, 2010; Saviotti and Pyka, 2013 or of financial stress testing Poledna, Thurner, Farmer, and Geanakoplos, 2014; Tedeschi, Iori, and Gallegati, 2012.

References

Axelrod, R. (1984). *The evolution of cooperation*. New York: Basic Books.

Borrill, P. L. & Tesfatsion, L. (2011). Agent-based modeling: the right mathematics for the social sciences? In J. B. Davis & D. W. Hands (Eds.), *The elgar companion to recent economic methodology* (pp. 228–258). Northampton, MA: Edward Elgar.

Delli Gatti, D., Gaffeo, E., Gallegati, M., Giulioni, G., & Palestrini, A. (2008). *Emergent macroeconomics: an agent-based approach to business fluctuations*. Milan etc.: Springer.

Dosi, G., Fagiolo, G., & Roventini, A. (2010). Schumpeter meeting keynes: a policy-friendly model of endogenous growth and business cycles. *Journal of Economic Dynamics and Control*, *34*(9), 1748–1767. doi:http://dx.doi.org/10.1016/j.jedc.2010.06.018

Downey, A., Elkner, J., & Meyers, C. (2002). *How to think like a computer scientist learning with python.(1era ed.)* Updated (2012) html version available online: http://openbookproject.net/thinkcs/python/english2e/. Wellesley, MA: Green Tree Press.

Elsner, W., Heinrich, T., & Schwardt, H. (2015). *The Microeconomics of Complex Economies: Evolutionary, Institutional, Neoclassical, and Complexity Perspectives*. Elsevier/Academic Press.

Epstein, J. M. (2006). *Generative social science: studies in agent-based computational modeling*. Princeton, NJ: Princeton University Press.

Isaac, A. G. (2008). Simulating evolutionary games: a python-based introduction. *Journal of Artificial Societies and Social Simulation*, *11*(3), 8.

Macal, C. M. & North, M. J. (2010). Tutorial on agent-based modelling and simulation. *Journal of simulation*, *4*(3), 151–162.

Nelson, R. R. & Winter, S. G. (1974). Neoclassical versus evolutionary theories of economic growth: critique and prospectus. *Economic Journal*, *84*(336), 886–905.

Nelson, R. R. & Winter, S. G. (1982). *An evolutionary theory of economic change*. Cambridge: Harvard University Press.

Poledna, S., Thurner, S., Farmer, J. D., & Geanakoplos, J. (2014). Leverage-induced systemic risk under basle ii and other credit risk policies. *Journal of Banking & Finance*, *42*, 199–212.

Pyka, A. & Fagiolo, G. (2005, February). Agent-based modelling: a methodology for neo-Schumpeterian economics. In H. Hanusch & A. Pyka (Eds.), *The elgar companion to neo-schumpeterian economics*. Cheltenham: Edward Elgar.

Saviotti, P. P. & Pyka, A. (2013). From necessities to imaginary worlds: structural change, product quality and economic development. *Technological Forecasting and Social Change*, *80*(8), 1499–1512. doi:http://dx.doi.org/10.1016/j.techfore.2013.05.002

Schelling, T. C. (1971). Dynamic models of segregation. *Journal of Mathematical Sociology*, *1*, 143–186.

Silverberg, G. & Lehnert, D. (1993). Long waves and 'evolutionary chaos' in a simple Schumpeterian model of embodied technical change. *Structural Change and Economic Dynamics*, *4*(1), 9–37. doi:DOI:10.1016/0954-349X(93)90003-3

Tedeschi, G., Iori, G., & Gallegati, M. (2012). Herding effects in order driven markets: the rise and fall of gurus. *Journal of Economic Behavior & Organization*, *81*(1), 82–96.