Rev Austrian Econ (2017) 30:19–38
DOI 10.1007/s11138-016-0354-z

Towards a New Austrian Macroeconomics

Vipin P. Veetil[1] · **Lawrence H. White**[1]

Published online: 16 July 2016

Abstract Austrian macroeconomists of the interwar period saw the economy as a complex adaptive system, in which macroeconomic variables emerge from the interaction between millions of purposefully acting agents. Recent advances in computation technology allow us to build empirically salient synthetic economies *in silico*, and thereby formalize many Austrian insights. We present a workhorse model with firms on an input-output network. Macroeconomic variables evolve through the interaction between micro-economic decisions. We use the model to explain an effect of monetary shocks on the price distribution and provide a sketch of other potential applications.

Keywords Macroeconomics · Agent-based model · Schumpeter · Mises · Hayek · Business cycles · Cantillon effect

JEL classification E00 · E14 · E30 · E40

> What our time needs most and lacks most is the understanding of the process which people are passionately resolved to control (Schumpeter 1939, p. vi).

1 Introduction

In standard Neoclassical and New Keynesian DSGE macroeconomic models, the US economy of 6 million firms and 120 million workers is treated as a Robinson Crusoe

✉ Vipin P. Veetil
vpudiyad@gmu.edu

Lawrence H. White
lwhite@gmu.edu

[1] Department of Economics, George Mason University, Fairfax, VA 22030, USA

economy of one household. Major shortcomings of such an approach have become obvious with its inability to explain the housing boom and resulting financial crisis and recession of 2007–09.Only since the crisis have macroeconomists begun to recognize that complex market interactions among a multiplicity of agents might be important for explaining aggregate outcomes (Gabaix 2011; Acemoglu et al. 2012).

The Austrian tradition in macroeconomics, by contrast, stresses that the movement from micro to macro involves an increase in the complexity of the phenomena under study (Lewis 2012; Axtell 2014). In his Nobel lecture F. A. Hayek (1989), referring specifically to the problem of explaining unemployment in a recession, emphasized that "the social sciences, like much of biology but unlike most fields of the physical sciences, have to deal with structures of essential complexity, i.e. with structures whose characteristic properties can be exhibited only by models made up of relatively large numbers of variables." To explain "phenomena of organized complexity" in an economy we need more than statistical relations among aggregates as used in standard macroeconomics. The character of a complex interactive system depend "not only on the properties of the individual elements of which they are composed, and the relative frequency with which they occur, but also on the manner in which the individual elements are connected with each other."

Here lies a challenge. Can we write down models made up of large numbers of agents, explicitly and reasonably specifying the manner in which they interact, that yield emergent results reproducing the characteristic properties of the macroeconomy? The models that Austrians like Friedrich Hayek, Ludwig von Mises, Joseph Schumpeter, and more recently Roger Garrison (2001), have traditionally employed to understand business cycles have been almost entirely verbal and graphical. Here we propose that progress can be made in understanding the organized complexity of the macroeconomyby exploiting the technique of building agent-based models that we can calibrate and use to simulate macroeconomic time series.

We call this approach "New Austrian Macroeconomics." In the sections that follow we discuss the background and motivation for the approach, provide the specific working example of a "workhorse" agent-based macro model that displays short run monetary non-neutrality (Taghawi-Nejad and Veetil 2016), and consider the prospects for modifying the model to capture other macroeconomic phenomena.

2 The Austrian school of thought in macroeconomics

The term "school of thought" is used to refer to two distinct objects: a sociological entity and an intellectual entity. A sociological school of thought has one master and one doctrine, with a core group, zones of influences, and outer fringes. An intellectual school of thought is a closely connected web of ideas in whichmembers share a pre-analytic vision, agree on "what are the questions", and do not differ gravely on practical wisdom (though they may differ on public policy). The Ricardians of nineteenth century were a school of thought in both senses. So too were the early Keynesians, with Keynes the master, his *General Theory* the doctrine, andacore group gathered at Cambridge. The early Keynesians shared a belief in the need to save the capitalist economy from itself, and in the ability of policy-makers to do sothrough macroeconomic policiesacting upon aggregate variables. The hydraulic machine built by A. C. Phillips stands as an emblem of these beliefs (Barr 1988).

The Austrian macroeconomists of the interwar years, especially if we include Schumpeter in the group, did not constitute a school of thought in the sociological sense. Schumpeter, Mises, and Hayek were all masters in their own right. Their spheres of influence were different. Mises producedsome disciples in the United States. But neither Schumpeter nor Hayek produced men more faithful to their Master than their Science, an achievement in its own right.

The Austrians did however form a school of thought in the intellectual sense. Schumpeter, Mises, and Hayek and their followers sharedthe belief that macroeconomic turbulence was a consequence of plan failures. Lionel Robbinsfamously characterized a recession as "a cluster of errors." But they differed on its origins, mechanisms, and consequences (Veetil and Wagner 2015). Schumpeter, Mises, and Hayek saw an economy as an ecology of interconnected plans coordinated by the price system more or less effectively (Wagner 1999, 2012). Austrian business cycle theory is essentially a theory of why and how plan failures arise in an economic system. For Mises and Hayek, plan failures arise when the price system is distorted by central bank intervention. For Schumpeter, plan failures arise because innovation disrupts routines and the price system. Schumpeter, Mises, and Hayek were concerned with the origin, propagation, and resolution of miscoordination among the plans of economic agents.

The Austrians saw macroeconomic variables as emergent outcomes of microeconomic interactions. Macro variables do not have a life of their own, they neither choose, nor can be chosen. While modern macroeconomics began its quest for microfoundations in the 1970s (Weintraub 1979), Austrian macroeconomics was always micro-founded. They did not accept as explanatoryany theory without human agency, in which macro variables merely act upon each other, as in the Y = C + I + G + NX or MV = PQ account of a macro economy. For the Austrians, macroeconomic turbulence reflects micro-economic problems. Schumpeter, Mises, and Hayek recognized that the interaction between economic agents produce phenomena that may not be present at the level of individuals, or even in smaller groups, because scale matters (Hayek 1964; Axtell 2006). In complex systems, scale matters because individual elements are interdependent and self-organizing, and the nature of relations amongindividuals changes as the number of elements in the system grows. We should expect the macroeconomic phenomena of an economy with 1 individualto be very different from that of an economy with 100 million individuals.

Hayek's (1964, p. 333) definition of a complex social system hinges on the question of how relations between elements change with scale, as explained in the following passage.

> There seems to exist a fairly easy and adequate way to measure the degree of complexity of different kinds of abstract patterns. The minimum number of elements of which an instance of the pattern must consist in order to exhibit all the characteristic attributes of the class of patterns in question appears to provide an unambiguous criterion.

Social regularity does not require individual regularity. For instance, the size distribution of firms in the United States is relatively stable, though on average every month a hundred thousand firms are founded and equal numbers collapse. Similarly, in the United States, the flux in the labor market dwarfs the changes in aggregate employment. In a typical year, nearly a third of those employed move from one employer to another (Fallick and Fleischman 2004). Nearly half of these workers change jobs across broadly defined industries (Bjelland et al. 2011). About as many workers, move from employment to the unemployment pool, and a comparable number move from and to the labor pool (Fallick and Fleischman 2004). All this means that the US labor pool churns over more than once in a single year, a frequencythat labor economist Robert Hall (1999, p. 1151) called “astonishingly high”.

Macroeconomic stability can emerge without the fixity of micro economic entities. Furthermore, it can emerge without the classical law of large numbers, which does not apply in a complex economy because the behavior of microeconomic entities is not independent from one other. The stability of macroeconomic aggregates reflects deep underlying social processes, which involve the structure of interactions between economic agents. The structure of relations among economic agents emerges out of agent-level decisions, for instance the topology of the buyer-seller network of the US economy is an outcome of local decisions of millions of firms. Concomitantly, agent-level decisions are influenced by the structure of relations among agents, for instance the profitability of a firm (or its very existence) may depend on the profitability of a supplier, andon the decisions of a supplier’s supplier. There are microfoundations to macroeconomics and macrofoundations to microeconomics, where ‘macrofoundations of microeconomics’ means the impact of different structural relations between micro-economic agents on the dynamics of macroeconomic aggregates.

Schumpeter, Mises, and Hayek were well ahead of their time inthinking of the economy as a complex adaptive system, in which the structure of relations between firms matters. This is the key “Austrian” element in what we call New Austrian Macroeconomics. We do not suggest that Schumpeter, Mises, and Hayek agreed on all matters of significance. Among other issues, the three had different views on macroeconomic policy. Mises came closest to a laissez-faire policy outlook. Hayek proposedactive central bank policy to prevent the self-amplification of a depression through a cumulative process, what he and other Austrians called a secondary depression (White 2008). Schumpeter (1939, p. vi) remarked that his own “analysis can in fact be used to derive practical conclusions of the most conservative as well as the most radical complexion”.

The three Austrians differed less on matters of practical wisdom. None had muchfaith in the ability of government spending to prod an economy out of recession, as exemplified by the following passage from Schumpeter’s (1936, p. 795) review of Keynes’ *General Theory*:

> The less said about the last book the better. Let him who accepts the message there expounded rewrite the history of the French ancien regime in some such terms as these: Louis XV was a most enlightened monarch. Feeling the necessity of stimulating expenditure he secured the services of such expert spenders as Madame de Pompadour and Madame du Barry. They went to work with unsurpassable efficiency. Full employment, a maximum of resulting output, and general wellbeing ought to have been the consequence. It is true that instead

we find misery, shame and, at the end of it all, a stream of blood. But that was a chance coincidence.

2.1 Mises and Hayek's theory of macroeconomic turbulence

Mises (1934) and Hayek (1931, 1939, 1941) constructed their theory of the business cycle from British CurrencySchoolideas of self-reversing monetary disturbances, combined with the Swedish economist Knut Wicksell's distinction between market and "natural" rates of interest and the earlier Austrian economist Eugen von Böhm-Bawerk's capital theory. The key to explaining the "cluster of errors" was to show how monetary disturbances that distorted interest rates prompted more investors to launch unsustainable investments. (The following summary draws heavily on White 2012, pp. 73–82).

Mises and Hayek supposed that the central bank either lowers the market rate of interest below the unchanged natural rate, or keeps the market rate from rising with the natural rate, where the natural rate of interest means the rate consistent with intertemporal meshing of plans between savers and investors. A too-low interest rate gives the appearance of new profitability (positive present value) to projects unprofitable at higher rates. The expansion of credit allows investors to finance the newly profitable-in-appearance projects. Profitability disappears when the interest rate rises to equilibrium, as it must because monetary shocks have only temporary real effects. At that point it becomes clear that, Mises' words, "the false impression of 'profitability' created by the credit expansion has led to unjustified investments." In elaborating the theory, Hayekdescribed how the mistaken investments during the boom distort the economy's "structure of production" away from its sustainable equilibrium configuration. Some sectors are over-expanded and some are starved for inputs.

The problem caused by the distortion of the interest rate can be described as a mismatchbetween the plans of savers and the plans of investors. The time-profile of consumable output that the business sectoras a whole is planningno longer matches the public's planned time-profile of savings and consumption across the same periods. Investment is especially skewed toward the "earlier stages" of production, meaning projects such as mineral extraction, heavy industry, and building construction that will yield consumable output only in relatively distant future periods. The economy is too "top-heavy" with activity far removed in time from final consumption, because those are the most interest-sensitive activities. Expectations of profitability based on a distorted interest rate signal are bound to be disappointed (Hayek 1933). The mismatch is revealed in the bust that occurs when a cluster of new investment projects cannot be profitably completed once the interest rate returns to equilibrium are finally terminated.

The Mises-Hayek theory was first and foremost a theory of the "upper turning point": it aimed to explain why the cheap-credit boom gives way to bust (Garrison 1984). In this way it offered an explanation for the 1929 downturn in the US and world economies that began the Great Depression. In the same way its modern proponents see it as an explanation for the formation and bursting of the housing bubble that preceded the Great Recession.

2.2 Schumpeter's theory of macroeconomic turbulence

For Schumpeter, plan failures arise because of the continual injection of new entrepreneurial plans into the drama of economic life. The discovery of new products, new markets, and new ways of doing things upset cost calculations, which lead to the failure of some plans. If indeed the plans of different economic agents are independent of each other, then the Law of Large Numbers guarantees that the failure of some plans will be compensated for by the success of others. But the classical Law of Large Numbers does not hold in a system of interdependent plans. One plan failure can lead to the failure of another plan, producing cascades of failures. The size of the cascades of plan failures depends on the state of the system. Schumpeter did not produce a theory of what determines the size of cascades, which is a matter of great importance because only cascades of large sizeswill appear in macroeconomic data.

In the years since Schumpeter's work on macroeconomic turbulence, physicists (Bak et al. 1993) and biologists (Kauffman and Johnsen 1991) have made discoveries significant for developing Schumpeter's cycle theory. One such discovery is notion of self-organized criticality. A system is said to be in a *sub-critical state* when small changes in the properties of parts produce small changes in the properties of the system. When a system is in a sub-critical state, large micro-changes are necessary to produce large macro-changes. A system is in a *super-criticalstate* when small changes in the properties of the parts produce large changes in the property of the system. A system is in a *critical state* when small changes in parts produce changes of all scales at the system level. While most micro changes will produce small macro changes, some micro changes will produce large macro changes. Perhaps this is what Schumpeter (1939, p. 87) meant by the "extreme sensitiveness" of the economic system to small changes. Often external tuning of parameters is necessary to hold a system in a critical state. However, for some systems the critical state is an attractor. The system self-organizes into a state of criticality. The prototypical example of a critical system is a sand pile, as explained in the following passage from Scheinkman and Woodford (1994, pp. 417–18).

> When the slope of the pile is nowhere too steep, dropping on additional grains of sand at randomly chosen sites has no macroscopic effects, as at most small numbers of grains will shift position in each case. However, randomly dropping on additional sand will eventually result in the slope of the pile increasing to a critical slope, at which point large avalanches can occur in response to the dropping of a single additional grain of sand. A sand pile with a slope that is initially greater than the critical slope also evolves toward it. In this case through an immediate large avalanche that collapses the pile. Thus while the existence of macroscopic instability without large external shocks depend upon a particular critical slope, the system endogenously evolves toward exactly that state.

Schumpeter appears to have had an implicit notion of an economy as system exhibiting self-organized criticality. In a critical state, the discovery of new products, new markets, new ways of doing things, are capable of producing recessions and depressions. Though most entrepreneurial actions will register little change in macroeconomic variables, some actions will produce cascades generating booms and recessions. As to which entrepreneurial actions will generate recessions is difficult to predict because the attributes of the actions themselves are not sufficient statistic. As to whether an action generates a large cascade depends on the state of different parts of the system, their inter-relations, and where the entrepreneurial action originates. As Schumpeter (1939, p. 101) noted, the process of change set in motion by an innovation "is independent either of the size of the innovating firm or firms or the importance of the immediate effects their action would in itself entail".

Though Schumpeter did not explain why an economic system moves towards a state of criticality, Schumpeter's wasaware of the incompleteness of his theory of macro-economic turbulence. In the preface to *Business Cycles*, Schumpeter (1939, p. v) says, "The younger generation of economists should look upon this book merely as some-thing to shoot at and start form as a motivated program for further research". Despite its incompleteness, Schumpeter's sketch of the capitalist economic process comes closest to what may be called an endogenous theory of business fluctuations. Schumpeter's theory, if developed, may get us out of what Axtell (2007, p. 107) calls the "...the awkward situation of economists usually seeking the basis for economic change in non-economic phenomena".

3 What is new in "New Austrian Macroeconomics"?

Economics by its nature a quantitative science. Much of the economic world presents itself in form of prices and quantities, which are numericalexplananda. What is to be done to explain them is the difficult methodological question. A famous controversy of sorts exploded in the *Methodenstreit* or dispute over methodsbetween the Austrians and the German Historical School in the late nineteenth century. In the usual caricature of the dispute, Menger and his school championed theoreticaleconomics over non-generalizable history, while Schmollerchampioned historical economics over arid theory.

Whatever may be the actual details of the dispute and the verdict of the historians of economic thought, the notion of a conflict between theory and empirical work is unhelpful. Theory is indispensable. As Marshall (1897, p. 119) noted, one cannot go from the particular to the particular without going through the general. The collection of data is often shaped by some implicit or explicit notion of the working of the economic system. For instance, the development of national income accounting is closely associated with idea that aggregate variables act upon each other, and can be acted upon through government policy. Yet at the same time, facts about the world inevitably enter any explanatory theory. Empirical observationsgive the theorist parameters of individual behavior and institutional circumstances that describe the initial conditions of the system. Useful theory is colored by data, and useful data by theory.

Economistsface the problem of building empirically salient models to explain reality. Numerous examples from the history of economic analysis indicate that there are benefits to building models in formal languages. The application of calculus and other mathematical techniques has yielded useful resultsnot reached by verbal means or freehand diagrams.

Consider the problem of developing a precise and careful treatment of Schumpeter's cycle theory. As discussed in Section 2.2, the idea of self-organized criticality is central to Schumpeter's cycle theory. Developments in the theory of random matrices allow us to formally characterize whether an economic system moves to self-organized criticality. Imagine an economic system with many firms, say six million firms as in the United States. The firms are related to each other through an input-output network. The network of relations between firms can be represented by a matrix where the rows and columns have all firms in the economy, and each entry represent a direction of flow of goods between two firms. The matrix is not fixed, but changes over time as firms make decisions about how much to buy from existing partners, and whether to find new partners. The time path of the Eigenvalue of the matrix is an indicator of whether a system stays at the boundary of criticality. In this way the theory of random matrices helps in understanding the stability of an economic system.

Unlike mathematics and computer programs, natural languages did not emerge to solve the problems of science. It is difficult to state ones assumptionsprecisely in a natural language, and to carry on scientific discourse without getting bogged down by having to recreate "what the author had in mind". Mathematics and computer programs make arguments explicit and testable. Furthermore, in so far as economic arguments involve assumptions about parameters of various kinds, formal language forces the economist to make the parametric assumptions explicit. Argument made in natural languages run the risk of changing parametric assumptions from paragraph to paragraph, or worse still from sentence to sentence.

Hayek (1943) was of course critical of the inappropriate use of mathematical methods to study social sciences. It is indeed true that the success of a technique used in one area of knowledge does not guarantee its success in another area of knowledge. But conversely it does not guarantee its failure. Just because higher mathematics were first used by physicists does not mean that "there is anything specially 'physicalist' about" them (Schumpeter 1954, p. 18). It is as much a folly to exclude a tool, as it is to use one, simply because it isused elsewhere.

It is sensible to study an economic system "using tools dictated by the character of the economy, not those that dictate the economy's character" (Axtell 2007, p. 119). However, the origin of a tool has little to do with whether it suits the character of an economic system. Computing Eigenvalues of a random matrix does not mean assuming away the decision-making capacity of individual economic agents, nor does it imply any informational assumptions about the decision makers.

Mises (1949, p. 31) was right in saying that the "experience with which the science of human action have to deal with is always an experience of complex phenomena". And it is an error to generalize from a case study. Mises's (1949, p. 31) declaration that the "information conveyed by historical experience cannot be used as building material for the construction of theories" is a warning against crude induction. On the other hand the pure logic of choice in a one- or two-person world does not exhaust economic theory. Useful economic theory is the logic of choice with certain observationally basedauxiliary assumption about the individuals who make these choices, and certain empirically based assumptions about how individuals interact. The economic theory of human interactions must of necessity be builtwiththe information conveyed by broad historical experience (Hayek 1937).

All this means that the architecture of an economic theory can be tested in two distinct ways. The parametric assumptions that enter economic theory may be evaluated for their empirical accuracy. And the steps that use the parametric assumptions to produce economic outcomes may be tested for their logical validity. Often, it may not be possible to perform the two tests separately because historical data about all parameters may not be available. Therefore the economist faces the problem of jointly-testing the logical validity of his arguments and the empirical validity of the historical assumptions that enter his argument at every stage. There is nothing apodictic about economic theory that goes beyond the pure logic of choice. Economic theory constitutes “plausible reasoning” about historical circumstances and social processes (Polya 1968), mere conjecturesby economists far simpler than the system they study.

None of this is to deny the profound observation made by Hayek (1941, 1943) and Mises (1960) that social sciences begin with knowledge not available to the physical scientists. Social scientists theorize about human actors whose decision-making ways are to some extent accessible through introspection. When the social scientist looks upon an economy as if he were looking at bacteria in a petri dish, she throws out knowledge of great significance. But it would be a pity to throw out all other knowledge and merely use the knowledge that we have of other human beings in light of being humans ourselves. Reflecting on the economic problems of an isolated Robinson Crusoe, even after the arrival of Friday, is not a basis for understanding phenomena of multi-agent systems. In the midst of such complex problems, there is little reason to rule out any promising technique, method, or tool before giving it a try.

4 Agents-based modeling and New Austrian Macroeconomics

While Schumpeter, Mises, and Hayek produced profound insights on the workings of an economic system, they did not built formal models of economic processes that generate the statistical properties of empirically observed time series (Stock and Wattson 1998). This is as much a criticism of the masters as of Galileo for not having built the Hubble Telescope. The technology was simply not availableto build the models that Hayek (1989) presumably had in mind when he spoke of “models made up of relatively large numbers” of systematically connected agents. The most advanced technology of the interwar years was differential and difference equations. While differential equation models of aggregate variables may capture the time-series properties to be explained, from the Austrian point of view differential equation models by themselves do not constitute much of an explanation (Boettke and Veetil 2016).

It is only towards very end of the twentieth century that the technology to develop Hayekian ideas about complex systems began to develop. These came to be known as agent-based models. Agent-based models have the potential to “create contemporary analytics” for Austrian macro (Opera and Wagner 2003, p. 98). An agent-based model is a *synthetic* economypopulated by purposefully behaving agents, who make decisions based on limited information. The agents interact on networks, and sometimes form networks through bottom-up processes. In agent-based models economic actors can interact with each other, and are not limited to interacting with vectors of prices (Kirman 1997). The economic agents populating the synthetic economies may be consumers, firms, workers, government officials, and other decision-making entities.

A typical agent-based model has three parts (Macal and North 2010). The first part is a specification of individual agents. This includes description of their cognitive characteristics, access to information, and goals, all of which may vary across agents. The second part is a specification of the process of interactions between agents. And the third part is an environment through which or with which agents interact. The artificial economy is run forward in time and the data that emerges from agent-interactions is collected for inference (Axelrod 1997). Agent-based models are particularly useful to study problems that involve variables that are too few or too interdependent to make statistical mechanics appropriate, but too many to use nineteenth century mathematics (Weaver 1948). For a primer on agent-based models see: http://www2.econ.iastate.edu/tesfatsi/ace.htm.

Agent based modelsare useful to study systems that are difficult to characterize through analytical methods. Some systems resist full description through equations, while others are difficult to study by manipulating equations (Axtell 2000). For example, economists have studied a variety of phenomena including political competition by applying Hotelling's (1929) model of competition between two firms facing customers uniformly distributed along a line. But competition seldom occurs over just one attribute. Theoretical and practical questions called for a generalization of the Hotelling model along multi-dimensional space. However the model could not be generalized using analytical methods because when firms choose both location and price, it becomes difficult to compute the areas they serve. By using instead an agent-based approach, Ottino-Loffler et al. (2015) are able to generalize the model of spatial competition. They create a synthetic economy with firms who make both price and location choices. Agent-based models are a general-purpose technique.

As Hayek (1964) recognized decades ago, scale matters in social systems. There are good reasons to believe that the statistical properties of aggregate variables in an economy with 100 firms will be very different from that of an economy with 100,000 firms. Today, we can build synthetic economies that are full-scale replicas of real world economies. Consider Axtell's (1999) agent-based model of firm dynamics, which populates a synthetic economy with 120 million workers. The workers form firms because team production yields productivity gains. However, team production creates problems too. Workers have an incentive to shirk, and monitoring is costly. As team sizes grow larger, some workers shirk, which incentivizes others to shirk. Such firms produce low output per worker, causing some workers to leave for other firms or form new firms of their own. Under some parameter combinations, this simple dynamics reproduces over two-dozen facts about firm and labor market dynamics in the United States. These facts include firm size distribution, flow of workers from one firm to another, monthly creation of new firms, and age-distribution of firms (Axtell and Guerrero, Firm and labor dynamics, forthcoming).

A number of other agent-based model have been estimated to fit empirical data. Dean et al. (2000) provide an agent-based model that empirically fits the cultural dynamics of the Anasazi civilization. Geanakoplos et al. (2012) fit several aspects of pre and post crisis housing market dynamics using an agent-based model. Samanidou et al. (2007) fits several financial market time series using an agent-based model. For a discussion on the empirical validation of agent-based models see Windrum et al. (2007); Alfarano et al. (2005), and Janssen and Ostrom (2006). For a discussion of the micro-consistency of agent-based models that fit macroeconomic variables see Le Baron (2016).

Agent-based modes are typicallyestimated by simulation (McFadden and Ruud 1994). In the late 1980s, analytical modelsbecame too complicated to yield closed form solutions. This meant that they could not be estimated using traditional econometric techniques. Estimation by simulation arose as a response to the problem of estimating parameters of modelsthat do not yield closed form solutions. With agent-based models the problem of parameter estimation becomes even more complicated because they tend to violate one or more of the assumptions necessary for asymptotic and small-sample theorems about estimators to hold.

Estimation by simulation of agent-based models works in the following manner. One defines a distance between model output and real world data. The distance may be absolute value, sum of squared errors, or higher order moments. With multiple outputs, the distances between the different outputs of the agent-based model and real world data must be weighted. After defining the distance, one runs multiple iterations of the model and changes the parameter values to decrease the weighted distance. Some, if not most, parameters of an agent-based model are defined at the level of the individual. Changes in individual-level parameters alter individual behavior, which in turn changes the interactions between individuals and the aggregate variables that emerge from these interactions. We can estimate the parameters as long we have more data than parameters. McFadden and Ruud (1994) discusses how to estimate models without closed form solutions if we do not have many individual observations, but have data on several higher order moments. These are problems of yesteryears. We live in the world of big data. Axtell (2001) presents data on the population of firms in the United Stated, a matter that was well beyond the dreams of yesteryear economists. We have data on the input-output network for a subset of firms in Japan (Mizuno et al. 2014) and for all publically traded firms in the United States (Atalay et al. 2011).

Specification searching and post-hoc model construction threaten the robustness of agent-based model simulations, as they do to traditional econometric results (Leamer 1978). In a two parameters model that produces one time series, it may be possible to grid-search the parameter space and select the combination of parameters that minimize the distance between model output and in-sample real world data. A large-scale macroeconomic model of the US economy may involve a dozen or more parameters, and will produce several dozen time-series. The question of judgment enters the problem of parameter estimation. What should be the weights attached to errors associated with different time series? Should employment weigh more than inflation? Which parameters should be changed in which combinations? Should parameters changes in large steps, or small steps, or some combination of the two? Estimating parameters of an agent-based model requires judgment. As long as the judgments are transparent, robustness is open for assessment.

5 A workhorse new Austrian macro model: with an application

We describe here an agent-based "workhorse" model (for an extensive account see Taghawi-Nejad and Veetil (2016)) built on the standard model of monopolistic competition in the market for intermediate goods as generalized by Gualdi and Mandel (2015). Firms are related to each other through a weighted input-output network. The weights of the network represent the proportions in which firms buy inputs from each other. Each firm makes decisions based on local information. Profit maximizing firms determine prices as in standard models of monopolistic competition. Given factor prices charged by their network neighbors, firms maximize profits to determine the proportions in which to buy inputs from their neighbors. Prices and network weights emerge from the interactions between profit maximizing firms. We offer the next section to illustrate some of the basic functionalities of the model, and to motivate its future use for studying other macroeconomic problems. The model code is written in Python programming language and is available at https://bitbucket.org/VipinVeetil/cantillon. The model is about 800 lines of code.

Economists have long recognized that monetary shocks change the distribution of prices (Cantillon 1755, Edgeworth 1887, Keynes 1932, Mises 1949). But most theoretical models of monetary non-neutrality do not produce one of the observed relationships about monetary non-neutrality: some prices temporarily fall in response to expansionary monetary shocks (Bils et al. 2003, Lastrapes 2006; Balke and Wynne 2007; Baumeister et al. 2013). The input-output network model described earlier produces a fall in some prices in response to a money injection. No other model of monetary non-neutrality produces a fall in some prices in response to a money injection. In what follows we describe the process of money injection and the reasons for monetary non-neutrality.

New money is injected in some firms, increasing their nominal wealth. These firms increase their demand for inputs and thereby increase the nominal wealth of their suppliers. The money spreads through the network as firm changes their demand and supply decisions. Figure 1 presents a histogram of price changes five time steps are a monetary shock (a 10 % increase in the stock of money). The x-axis represents

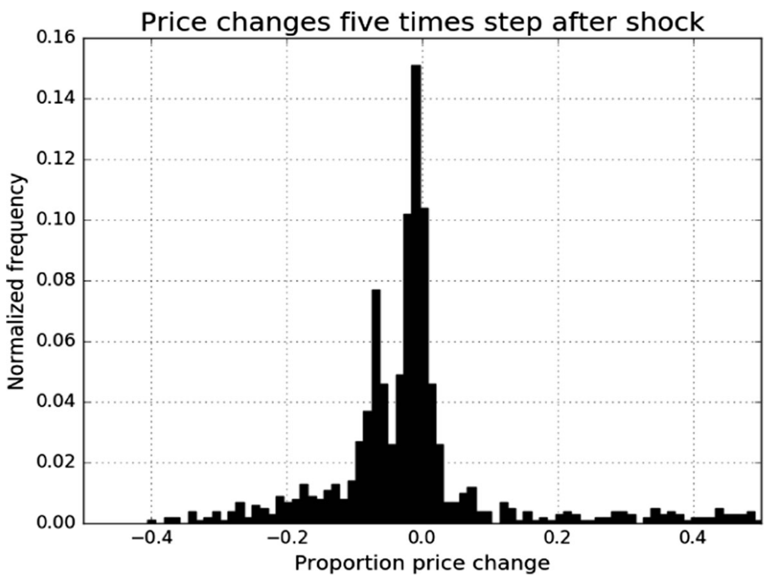

Fig. 1 Histogram of Accumulated Price Changes After Monetary Shocks.

proportion change in prices, for example 0.25 means the price is 25 % greater than the price before money injection. The y-axis represents normalized frequency. Some values of the x-axis are negative because some firms decrease prices in response to a money injection in the economy.

The economic intuition behind the decrease in some prices in response to a money injection is the following. Imagine a system with four firms: *a*, *b*, *c*, and *d*, as shown in Fig.2 The arrows between firms indicate the direction of the flow of demand: *a* buys input from *b*, *c* buys inputs from *b* and *d*. Suppose *a* receives a money injection, and as a consequence increases demand for inputs from *b*. The increase in demand for *b*'s output leads to an increase in the price of *b*'s output. Since *c* buys inputs from *b*, *c* experiences an increase in price of an input. As to how *c* responds to an increase price of an input depends on the income effect and substitution effect. The income effect would cause *c*to decrease the demand for input it buys from *d*. The substitution effect would cause *c* to increase the demand for input it buys from *d*. If the income effect overwhelms the substitution effect, *c* will reduce the demand for the input it buys from *d*. If *c* reduces demand for the input it buys from *d*, then *d* experiences a fall in the demand for its output. In response to the fall in demand, *d* reduces the price for its output. Ultimately, a money injection in *a* leads to a fall in price of the good produced by *d*. In the model economy with 1000 firms, as to which prices fall depends on the network of relations between firms. For instance, *d* may not decrease its price in response to a decrease in demand from *c* if *d* experiences an increase in demand from another firm *e* (not in Fig 2). The topology of interaction between firms, and the firms through which money is injected, determines which firms decrease prices and by how much. Mises (1949, p. 410) in the following passage lucidly describesthe mechanism our model lays out:

> ...we must never forget that changes in the quantity of money affect prices in an uneven way. It depends on the data of each particular case at what moment and to what extent the prices of the various commodities and services are affected. In the course of a monetary expansion (inflation) that first reaction is not only that the prices of some of them rise more quickly and more steeply than others. *It may also occur that some fall at first as they are for the most part demanded by those groups whose interests are hurt* (italics added)

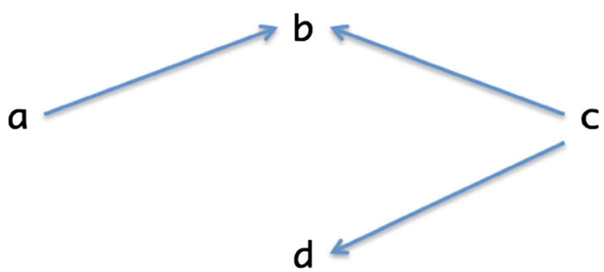

Fig. 2 Sample Relations Between Firms in a Production Network.

6 Open questions: three potential applications of our new Austrian macro model

First, the workhorse model can be developed to study Mises's (1949) ideas on business cycles. The version of our model used to study the effect of monetary shocks on the distribution of prices does not have capital goods, time structure of production, or interest rate, all of which can be introduced without much difficulty. Firms may use capital to produce goods, with different kinds of capital lasting for different time periods; one way to do this is to incorporate heterogeneous depreciation in capital goods. Firms may be connected to each other in such a way that some firms produce higher-order goods and other produce lower-order goods. And finally, a market for loanable funds can be introduced where households place savings and firms place demands for savings. The central bank may from time to time intervene in the market for loanable funds to distort the rate of interest. Furthermore, central bank intervention can be made a function of the state of the economy, thereby partly endogenizing central bank decision-making.

We are likely to gain two insights from developing an agent-based model of Mises's cycle theory. One, we will be in a position to answer the question of what proportion of real world macro-economic dynamics is explained by Mises's cycle theory. In other words, what is the empirical relevance of Mises's dynamics? This can be done by calibrating the model to real world data, while considering other potential explanations of macroeconomic dynamics. Two, we will develop some understanding of the role of entrepreneurial expectations in Mises cycle theory. Cowen (2002) has argued that Mises's dynamics are neutered by entrepreneurial forward-looking expectations. It should not take too much intelligence, at any rate far less than the Austrians typically ascribe to the entrepreneur, to decipher interest rate changes due to changes in time-preference or money-demand shocks from those due to central bank intervention. After all, the central bank 'announces' interest rate changes. We believe that Mises's dynamics are neutered by the availability of aggregate data if the analysis is presented in representative agent or IS-LM style models (Opera and Wagner 2003, p. 103). However, Misesian dynamics are not neutered in an agent-based setting because to neuter the dynamics firms will have to form expectations about all the prices change in the economic produced by interest rate changes (Holcombe 2016).

Second, our model can be used to shed light on the debate on monetary policy rules versus discretion. Traditionally, it has been believed that monetary policy rules provide more stable environment for economic decision-making than discretionary monetary policy. The belief is based on the idea that monetary policy rules make it less costly for economic agents to form accurate expectations about aggregate variables. For instance, if the Federal Reserve increases money supply at a rate of 3 % per year, agents can form reasonable expectations about price level, thereby avoiding problems that arise when agents misperceive price level changes as being relative price changes. This view of monetary policy rules is based on models in which economic decisions are based primarily on attributes of the agents themselves and their expectations about aggregate variables. In a decentralized economic system, agents form expectations about a whole host of variables, many of which are local. In fact, most economic agents possibly care more about local variables than aggregate variables. There is little reason to believe that monetary policy rules defined on aggregate variables lend stability to an economic system, in which the decisions on economic agents will be influenced by the way in which the rule affects local variables. Policies that stabilize aggregate variables may produce disturbance at the local level, which in turn may disturb micro decision-making, and produce instability in aggregate variables. This problem can be studied using our agent-based macro model. We can allow a central bank to inject money at different rates and in different ways. Furthermore, we can study how the rules performwhen a central bank has lagged and incomplete information about the state of the economy (Morgenstern 1950).

Third, our model can be used to understand the influence of monetary institutions on economic activity. Relative price effects of monetary injections are not conceptually limited to central banking; a system of completely private banking too will experience relative price effects if banks inject excess money. Likewise money demand shocks can occur under either regime. Yet the relative price effects, and the consequence of these relative price effects on the stability of the economic system may be different in the two systems. While several scholars have claimed that a private free banking system may be more stable than a central banking system, there are no formal models that have studied this claim or derived the conditions under which the claim it true. As a first step, we can build a private banking system by allowing multiple banksto inject money into different parts of the economy under competitive constraints. It will be interesting to see the extent to whichprivate bank money injections produce Mises style cycle as Hayek (1933) claimed.

7 On expectations and the dimension of economics problems

In 1975 Lucas presented a seminal model of macro-economic dynamics based on informational lags. In Lucas's Islands model agents face the problem of deciphering relative price changes from changes in the price level. Agents misperceive relative prices for the good they produce due to a lag in information about aggregate money supply. Lucasrenounced his Islands Model for good reason. Data on aggregate money supply are available at reasonably short intervals. The Federal Reserve publishes data on M1 every Thursday and data on M2 every Monday. The dynamics of Lucas's Island Model are neutered if agents have data on aggregate money supply and use it to form reasonable expectations about price level.

In contrast to Lucas's Islands Model, the dynamics of our input-output macro model are not neutered if agents have information on aggregate variables. Each firm's profit depends on the prices at which it buys inputs and the price at which it sells output. The changes in the prices that matter to a firm are not a trivial function of aggregate variables. Information about aggregate variables does not allow firms to predict the sequence of changes in the prices of different inputs and output.

The temporal sequence and direction of changes of all the different prices in the economy as a consequence of money injection depends on which firms receive the initial money injection, the topology of the network, and the state of each firm in the network. No firm has information about which firms receive new money, what they do with new money, and the inter-relations between different firms in an economy, all of which is necessary to predict the sequence of changes in the prices of its inputs and output. And even if each firm did have all the information it needs to compute the economy wide sequence of price changes, such computation would be practically impossible (Axtell 2005; Taghawi-Nejad and Veetil (Complexity of coordination, forthcoming)). The US economy has over six million firms connected through an intricate web of relations, with some firms near bankruptcy, others growing, still others considering new projects. No firm is capable of computing the time path of price changes in an economy due to the injection of new money. The problems solved through the interaction between economic agents are too complex for any single agent to solve even if he were to have all necessary information to solve the problem. As Vilfredo Pareto (1971, p. 171) notes, in such cases it is "political economy that comes to the aid of mathematics". Agents in our model form expectations about objectsthat are of relevance to them. Agents have heterogeneous expectations not only in the sense that different agents have different expectations about the same object, but also in the sense that different agents have expectations about different objects, as explained by Wagner (1999, p. 72) in the following passage.

> For someone who owns an auto repair shop and is trying to decide whether to expand his facility or to move to a new location where a larger facility is already in place, his expectation about the future general price level is surely far down his list of concerns, and may not appear at all. It would surely be the same for the vast preponderance of commercial decisions where people are making choices now to commit resources to particular uses, when the results will not be known until some future time. There would be many different particular objects of expectation, depending on the particular activity about which expectations are being formed.

Lucas did our science a favor by bringing expectations back to macroeconomics in heyday of Keynesian analysis. Lucas was quite right in noting that economic agents are forward looking. Few would disagree with Lucas's view that it is strange to presume public agents are free to change their choice variables in response to a change in information but private agents are contractually commitment to past, or that private agents do not consider volatility of variables that affect them while forming contracts. Sargent and Wallace (1976) have a point when they say that in a society where policy makers change rules, economic agents will tend to consider possible future rule changes while making plans for the future. Few can disagree with the following passage from Lucas (1976, p. 41), his famous Lucas Critique paper.

> This essay has been devoted to an exposition and elaboration of a single syllogism: given that tile structure of all econometric model consists of optimal decision rules of economic agents, and that optimal decision rules vary systematically with changes in the structure of series relevant to the decision maker, it follows that any change in policy will systematically alter the structure of econometric models.

Unlike the post-Keynesians (Crotty 1980) and others who were, and still are (Frydman and Phelps 2013, too keen on treating expectations as an external driving force of macroeconomic volatility, Lucas—like Schumpeter before him—thought expectation about economic variables was within the domain of economic analysis. Schumpeter criticized Keynes's treatment of expectations as exogenous variables that influence economic activity, as exemplified by the phrase “animal spirits”. Schumpeter (1939, p. 55) thought expectation cannot be treated like the taste of tobacco, but must be explained as a variable that co-evolves with macroeconomic circumstances.

We agree with Lucas when he says expectations are influenced by the economic environment. However,we do not believe economic agents can form “rational expectations” in Muth’s (1961) sense. The economy is far too complex for agents to estimate parameters of joint-distributions of all variables that matter. In a complex economy, rational expectations are not only computationally impractical, but its very pursuit may be irrational in the sense that it will not meet marginal cost calculus. Economic agents have no reason to gather information about the economy as a whole if they are incapable of processing it to form expectations. In a complex economy, the pursuit of rational expectations may be irrational. Sargent and Wallace (1976) are right in saying that economic agents consider possible rule changes when making plans, but the system is far too complex for them to compute the impact of future rule changes on their plans.

8 Concluding remarks

Macroeconomics has gone through much change in the last hundred years, so much so that macroeconomic theory appears more like an object of fashion than science. One of the reasons for the fads in macroeconomic theory is its close relation to policy making. The history of last hundred years illustrates that macroeconomists have fallen prey to Ricardian Vice: the practice of offering advice about a complex world based on simple models. Analysis that presumes governments directly act upon aggregate variables tell us little about what government can actually do. Yet the IS-LM model was usedto support interventionist policies. Analysis that uses a single agent to represent an economy with 6 million firms and 120 million workers cannot tell us much about how markets work. Yet representative agent models were used to argue for non-interventionist policies. Contemporary American Austrians too are guilty of the Ricardian Vice, perhaps just as much as New Classical and New Keynesian economists. Many American Austrians have argued for non-intervention during recessions and for ending the Federal Reserve, though no one has built an explicit Austrian model that produces a single time series, let alone the dozen or two regularities found in macroeconomic data. New Austrians must stay wary of the Ricardian Vice; it helps neither policy, nor theory, as Schumpeter (1936, p. 792) explains in the following passage.

> It is, however, vital to renounce communion with any attempt to revive the Ricardian practice of offering in the garb of general scientific truth, advice which whether good or bad carries meaning only with references to the practical exigencies of the unique historical situation of a given time and country. This sublimates practical issues into scientific ones, divides economists … according to lines of political preference, produces popular successes at the moment, and reactions after–witness the fate of Ricardian economics–neither of which have

anything to do with science. Economics will never have nor merit any authority until that unholy alliance is dissolved.

Nothing in a bottom-up view of an economic system suggests that policy will be neutral or ineffective. To say that a government cannot directly act upon aggregate variables is very different from saying government policy cannot change aggregate variables in "desirable"or "undesirable" directions. Our understanding of whether, how, and when government policy can influence an economic system depends on a reasonable view of a complex economic system, and a complex government bureaucracy which is intertwined with the economic system (Wagner 2014). It is such an understanding that we lack most at the moment.

Schumpeter, Mises, and Hayek had profound insights about the working of a decentralized economic system. Today, we have the computational technology to build large-scale empirically salient models of a macro economy. Add to this, the growing appetite within the economics profession (Caballero 2010), and more so among policy makers for new ways of thinking about the macro economy. In the same way that IS-LM is now passé, the representative-agent model (with and without price stickiness) may disappear from graduate textbooks and policy organization. The question is what will replace these models? We see entrepreneurial profits waiting to be grasped.

References

Acemoglu, D., Carvalho, V. M., Ozdaglar, A., & Tahbaz-Salehi, A. (2012). The network origins of aggregate fluctuations. *Econometrica, 80*(5), 1977–2016.

Alfarano, S., Lux, T., & Wagner, F. (2005). Estimation of agent-based models: the case of an asymmetric herding model. *Computational Economics, 26*(1), 19–49.

Atalay, E., Hortacsu, A., Roberts, J., & Syverson, C. (2011). Network structure of production. *Proceedings of the National Academy of Sciences, 108*(13), 5199–5202.

Axelrod, R. (1997). Advancing the art of simulation in the social sciences. *Simulating Social Phenomena, 456*, 21–40 Springer.

Axtell, R. (1999). The emergence of firms in a population of agents: local increasing returns, unstable Nash equilibria, and power law size distributions. Center on Social and Economic Dynamics, Brookings Institution Working Paper 3.

Axtell, R. (2000). Why agents?: on the varied motivations for agent computing in the social sciences. Center on Social and Economic Dynamics, Brookings Institution Working Paper 17.

Axtell, R. L. (2001). Zipf distribution of US firm sizes. *Science, 293*(5536), 1818–1820.

Axtell, R. (2005). The complexity of exchange. *The Economic Journal, 115*(504), F193–F210.

Axtell, R. L. (2006). Multi-agent systems macro: a prospectus. Post-Walrasian Macroeconomics. Cambridge University Press.

Axtell, R. L. (2007). What economic agents do: how cognition and interaction lead to emergence and complexity. *The Review of Austrian Economics, 20*(2–3), 105–122.

Axtell, R. (2014). Hayek enriched by complexity enriched by Hayek. Presented at the conference "40 Years After the Nobel: F.A. Hayek and Political Economy as a Progressive Research Program," Mercatus Center, George Mason University, October 2–5, 2014.

Bak, P., Chen, K., Scheinkman, J., & Woodford, M. (1993). Aggregate fluctuations from independent sectoral shocks: self-organized criticality in a model of production and inventory dynamics. *Ricerche Economiche, 47*(1), 3–30.

Balke, N. S., & Wynne, M. A. (2007). The relative price effects of monetary shocks. *Journal of Macroeconomics, 29*(1), 19–36.

Barr, N. (1988). The Phillips machine. *LSE Quarterly, 2*(4), 305–337.

Baumeister, C., Liu, P., & Mumtaz, H. (2013). Changes in the effects of monetary policy on disaggregate price dynamics. *Journal of Economic Dynamics and Control, 37*(3), 543–560.

Bils, M., Peter J. K., and Oleksiy K. (2003). "Sticky prices and monetary policy shocks." *Federal Reserve Bank of Minneapolis Quarterly Review, 27*(1), 2–9.

Bjelland, M., Fallick, B., Haltiwanger, J., & McEntarfer, E. (2011). Employer-to-employer flows in the United States: estimates using linked employer-employee data. *Journal of Business & Economic Statistics, 29*(4), 493–505.

Boettke, P. J., and V. P. Veetil. (2016). Models of human action. Cosmos +Taxis.

Caballero, R. J. (2010). Macroeconomics after the crisis: time to deal with the pretense-ofKnowledge syndrome. *Journal of Economic Perspectives, 24*(4), 85–102.

Cantillon, Richard. 1755. Essai Sur La Nature Du Commerce En General. Éditions de l'Institut National d'Études Démographiques 27, rue du Commandeur – 75675 PARIS Cedex 14 – France.

Cowen, T. (2002). Risk and business cycles: new and old Austrian perspectives. Routledge.

Crotty, J. R. (1980). Post-Keynesian economic theory: an overview and evaluation. *The American Economic Review, 70*(2), 20–25.

Dean, J.S., G. J. Gumerman, J. M. Epstein, Robert L. Axtell, Alan C. Swedlund, Miles T. Parker, and Stephen McCarroll. (2000). Understanding Anasazi culture change through agent-based modeling. Dynamics in human and primate societies: Agent-based modeling of social and spatial processes 179–205.

Edgeworth, F. Y. (1887). "Measurement of change in value of money." First Memorandum presented to the British Association for the Advancement of Science. *Reprinted in his Papers Relating to Political Economy, 1*, 198–259.

Fallick, B., and Fleischman C. A. (2004). Employer-to-employer flows in the US labor market: the complete picture of gross worker flows. Social Science Research Network.

Frydman, R., and Phelps E. S. (2013). Rethinking expectations: the way forward for macroeconomics. Princeton University Press.

Gabaix, X. (2011). The granular origins of aggregate fluctuations. *Econometrica, 79*(3), 733–772.

Garrison, R. W. (1984). Time and money: the universals of macroeconomic theorizing. *Journal of Macroeconomics, 6*(2), 197–213.

Garrison, R.W., (2001). Time and money: the macroeconomics of capital structure. Routledge.

Geanakoplos, J., Axtell, R., Farmer, D. J., Howitt, P., Conlee, B., Goldstein, J., Hendrey, M., Palmer, N. M., & Yang, C.-Y. (2012). Getting at systemic risk via an agent-based model of the housing market. *The American Economic Review, 102*(3), 53–58.

Gualdi, S., and Mandel A. (2015). On the emergence of scale-free production networks. Cornell University Library, available online at: http://arxiv.org/abs/1509.01483.

Hall, R. E. (1999). Labor-market frictions and employment fluctuations. *Handbook of Macroeconomics, 1*, 1137–1170.

Hayek, F. A. (1931). Prices and production. Augustus M. Kelly

Hayek, F. A. (1933). Monetary Theory and the Trade Cycle.Jonathan Cape

Hayek, F. A. (1937). Economics and knowledge. *Economica, 4*(13), 33–54.

Hayek, F. A. (1939). Profits, Interest, and Investment: And other essays on the theory of industrial fluctuations. London: George Routledge & Sons Ltd.

Hayek, F. A. (1941). The counter-revolution of science. *Economica, 8*(31), 281–320.

Hayek, F. A. (1943). Scientism and the study of society: part II. *Economica, 10*(37), 34–63.

Hayek, F. A. (1964). The theory of complex phenomena. *The Critical Approach to Science and Philosophy*, 332–349.

Hayek, F. A. (1989). The Pretence of knowledge. *American Economic Review, 79*(6), 3–7.

Holcombe, R. (2016). Malinvestment. The Review of Austrian Economics.

Hotelling, H. (1929). Stability in competition. *The Economic Journal, 39*(153), 41–57.

Janssen, M. A., & Ostrom, E. (2006). Empirically based, agent-based models. *Ecology and Society, 11*(2), 37.

Kauffman, S. A., & Johnsen, S. (1991). Coevolution to the edge of chaos: coupled fitness landscapes, poised states, and coevolutionary avalanches. *Journal of Theoretical Biology, 149*(4), 467–505.

Keynes, J. M. (1932). Social consequences of changes in the value of money. In Essays in Persuasion, pp. 59–75. Palgrave Macmillan.

Kirman, A. (1997). The economy as an evolving network. *Journal of Evolutionary Economics, 7*(4), 339–353.

Lastrapes, W. D. (2006). Inflation and the distribution of relative prices: the role of productivity and money supply shocks. *Journal of Money, Credit and Banking, 38*(8), 2159–2198.

Le Baron, Blake. (2016). Microconsistency in simple empirical agent-based financial models. Working Paper.

Leamer, E. E. (1978). Regression selection strategies and revealed priors. *Journal of the. American Statistical Association, 73*(363), 580–587.

Lewis, P. (2012). Emergent properties in the work of Friedrich Hayek. *Journal of Economic Behavior & Organization, 82*(2), 368–378.
Lucas, R. E. (1976). . Econometric policy evaluation: A critique. *In Carnegie-Rochester Conference Series on Public Policy, 1*, 19–46 North-Holland.
Macal, C. M., & North, M. J. (2010). Tutorial on agent-based modelling and simulation. *Journal of Simulation, 4*(3), 151–162.
Marshall, A. (1897). "The old generation of economists and the new." *The Quarterly Journal of Economics, 11*(2), 115–135.
McFadden, D., & Ruud, P. A. (1994). Estimation by simulation. *The Review of Economics and Statistics, 76*(4), 591–608.
Mises, L. (1934). Theory of money and credit. Jonathan Cape Ltd.
Mises, L. (1949). Human action. Yale University Press.
Mises, L.. (1960). Epistemological problems of economics. Ludwig von Mises Institute.
Mizuno, T., Souma W., and Watanabe T. 2014. The structure and evolution of buyer-supplier networks. Plos One. 9(7):e100712.
Morgenstern, Oskar. (1950). The accuracy of economic observations. Princeton University Press.
Muth, J. F. (1961). Rational expectations and the theory of price movements. *Econometrica*. *Journal of the Econometric Society, 29*(3), 315–335.
Opera, R. D., & Wagner, R. E. (2003). Institutions, emergence, and macro theorizing. *The Review of Austrian Economics, 16*(1), 97–112.
Ottino-Loffler, B., Stonedahl F., Veetil V. P., and U. Wilensky. (2015). A General Model of Spatial Competition. George Mason University Working Paper in Economics No. 15–62.
Pareto, V. (1971). Manual of political economy. Augustus Kelley.
Polya, G. (1968). Mathematics and plausible reasoning: patterns of plausible inference. Princeton University Press.
Samanidou, E., ElmarZschischang, D. S., & Lux, T. (2007). Agent-based models of financial markets. *Reports on Progress in Physics, 70*(3), 409.
Sargent, T. J., & Wallace, N. (1976). Rational expectations and the theory of economic policy. *Journal of Monetary Economics, 2*(2), 169–183.
Scheinkman, J. A., & Woodford, M. (1994). Self-organized criticality and economic fluctuations. *The American Economic Review, 84*(2), 417–421.
Schumpeter, J. A. (1936). Review of Keynes's general theory. *Journal of the American Statistical Association, 31*(196), 791–795.
Schumpeter, J. A. (1939). Business Cycles: A theoretical, historical, and statistical analysis of the capitalist process. Originally published by McGraw-Hill. 2005 edition by Martino Publishing.
Schumpeter, J. A. (1954). History of economic analysis. Oxford University Press.
Stock, J. H, and M. W. Wattson. (1998). Business Cycle Fluctuations in US Macroeconomic Time Series. National Bureau of Economic Research Working Paper 6528.
Taghawi-Nejad, D., and V. P. Veetil. (2016). The effects of monetary shocks on the distribution of prices. Working Paper.
Veetil, V. P., and Wagner R. E. (2015).Treating macro theory as systems theory: How might it matter?. In new thinking in Austrian political economy, pp. 119–143. Emerald Group Publishing.
Wagner, R. E. (1999). Austrian cycle theory: saving the wheat while discarding the chaff. *Review of Austrian Economics, 12*, 65–80.
Wagner, R. E. (2012). A macro economy as an ecology of plans. *Journal of Economic Behavior & Organization, 82*(2), 433–444.
Wagner, R. E. (2014). Entangled political economy: A keynote address. *Advances in Austrian Economics, 16*, 15–36.
Weaver, W. (1948). "There is a large literature on the subject of complexity, for example." *Science and Complexity, 36*, 536–544.
Weintraub, E. R. (1979). Microfoundations: the compatibility of microeconomics and macroeconomics. Cambridge University Press.
White, L. H. (2008). Did Hayek and Robbins deepen the great depression? *Journal of Money, Credit and Banking, 40*(4), 751–768.
White, L. H. (2012). The clash of economic ideas: the great policy debates and experiments of the last hundred years. Cambridge University Press.
Windrum, P., Fagiolo, G., & Moneta, A. (2007). Empirical validation of agent-based models: alternatives and prospects. *Journal of Artificial Societies and Social Simulation, 10*(2). http://jasss.soc.surrey.ac.uk/10/2/8.html. Accessed 21 April 2016.