Agent Based Macro Modeling

Antoine Godin

Kingston University

These slides are based on the lecture given by Alessandro Caiani during the EAEPE workshop in November 2016

February 22, 2017

EC7025 - Economic Policy Modeling

Outline

Neoclassical Economics

Dissatisfaction with Neoclassical Economics:

- **internal consistency** of this models (e.g. Capital controversy, Paradox of Thrift)
- **empirical plausibility** of assumptions (Fully Rational-fully informed optimizing representative agents in a world of perfect competition, CES utility and production functions, exogenous money supply(money/deposit multipliers) etc.)
- **plausibility and validability of results** (Pareto Optimality, Mkt equilibrium efficiency, Stability, etc.)

Criticisms rising in the aftermath of the Great recession (2008): the fault of Neoclassical models (DSGE) have to be found not so much in their inability to anticipate the crisis, but rather in the fact that they exclude the very possibility of a crisis.

Neoclassicals critics of DSGE I

"**I do not think that the currently popular DSGE models pass the smell test**. They take it for granted that the whole economy can be thought about as if it were a single, consistent person or dynasty carrying out a rationally designed, long-term plan, occasionally disturbed by unexpected shocks, but adapting to them in a rational, consistent way... The protagonists of this idea make a claim to respectability by asserting that it is founded on what we know about microeconomic behavior, but I think that this claim is generally phony. The advocates no doubt believe what they say, but they seem to have stopped sniffing or to have lost their sense of smell altogether" **Robert Solow** 2010 at US Congress-hearing on macroeconomic models

"For more than three decades, **macroeconomics has gone backwards**" **Paul Romer** 2016 "The Trouble With Macroeconomics"

Dismiss DSGE and embrace "**IS-LMentary**" **Paul Krugman** - New York Times Blog debates

Neoclassicals critics of DSGE II

"The workhorse New Keynesian dynamic stochastic general equilibrium (DSGE) models [...] have been of **minimal value in addressing the greatest macroeconomic crisis...** " [Blanchard et al., 2012, p.57]. "Do DSGE Models Have a Future?" Yes, but they have to change a lot and ... "accept to share the scene with **other approaches to modelization**" **Olivier Blanchard** (2015)

"New classical and new Keynesian research has had little impact on practical macroeconomists who are charged with [...] policy. [...] From the standpoint of macroeconomic engineering, the **work of the past several decades looks like an unfortunate wrong turn**" **Mankiw [2006]**

Common features of today Neoclassical Economics

What types of models are "neoclassicals"?

- Micro: General Equilibrium Theory and Game-Theoretic models
- Macro: Micro-Founded GE models: Endogenous Growth Models, DSGE models(RBC models, NK-DSGE models).

Features:

- Rational, measurable, sortable, convex preferences
- Optimization (Utility, Profits)
- Full information Olympic Rationality (no computational or memory bounds)
- Rational Expectations (they know the model of the world)
- no interactions
- Acceptance of Lucas' critique
- Methodological individualism or Reductionism
- General Equilibrium

Microfounded Dynamic Stochastic General Equilibrium Models

Typical structure:

- A batch of representative...
  - Consumers with a CES Utility Function
  - Firms with a Cobb-Douglas Production Function with constant returns.
  - Financial intermediaries (only recently)
- whose behavior is formally derived from microfoundations: i.e. maximizing an objective function subject to an inter-temporal budget constraint (or technological constraint), having an certain (in most cases, infinite) lifetime horizon within...
- A competitive economy, but with a number of possible distortions such as: nominal rigidities, monopoly power, information problems.

These first order conditions yield a fully state-contingent plan for the representative agents' choice variables looking forward from the planning date and into the foreseeable future.

Microfounded Dynamic Stochastic General Equilibrium Models

Common features:

- Rational expectations are assumed: agents have a complete knowledge of the "model" of the economy and are thus able to assess the consequences of shocks which may buffet the economy. Therefore, representative agents have an optimal plan in response to the realization of such shocks, given their expectations.
- Models are estimated as a system, rather than equation by equation, through Bayesian techniques.
- Models' solution approximated using log-linearization techniques to analyze the behavior of the system *in a neighborhood* of the SS when hit by an exogenous or policy shock. Unstable paths are scrapped off.

Criticisms

This class of models criticized under many respect by many different school of thoughts since their very foundation.

We focus on 2 criticims and discuss how AB models and SFC models allow to overcome them.

- Money and finance in DSGE models.
- Microfoundation la Lucas, the problem of aggregation and the relationship between micro agents and systemic behaviors.

Outline

Shocks in DSGE models

One of the strongest criticisms against DSGEs was their **inability to deal with non-linearities**: using **log-linearization** around the steady state forcibly imposed a stability condition on the system which eliminates the possibility of multiple equilibria, sudden state transitions, and tipping-point phenomena [Rubio-Ramirez and Fernandez-Villaverde, 2004].

In DSGE models, **business cycles are the outcomes of shocks to the economy, the sources of which are not discussed**. DSGE modeling focuses on what happens when a random shock hits the economy, rather than analyzing them as the outcome of endogenous processes within an evolving economy.

Permanent Technology Shocks have positive **long run** real effects for instance. Monetary shocks have **short run** positive real effects (non-neutrality of money in the short run) in the presence of nominal wage rigidities.

Non-linearities through financial frictions

To take the lesson of the crisis on board several DSGE models started to **incorporate different types of non-linearities** in their models and adopt **non-linear solution methods** [Borogan Aruoba et al., 2006].

However, most efforts gone in including in the models a **financial sector and "financial frictions"** Brunnermeier et al. [2012].

Trade in certain assets cannot take place because **markets are incomplete**: there is no market at all for certain state-contingent assets, or parties are not willing to engage in certain contracts because of agency problems [Quadrini, 2011]. Typical financial frictions focus on some credit constraint.

In these cases, agents are unable to anticipate/postpone spending (for consumption or investment), or insure against uncertain events (to smooth consumption or investment), thus being **unable to enforce their optimal state-contingent plan** $\rightarrow$ Episodes of financial fragility

Banks intermediate?

Though being now able to mimic non-linear dynamics, DSGE models still rely on external shocks to explain the origin of those non-linearities: financial frictions DSGE models **still fail to understand the inherent nature of finance and money** [Werner, 2014, 2015].

Most of these models either assume that **banks are totally absent and all lending is direct**, or adopt the **loanable funds** approach which reduces the role of financial institutions to **mere intermediaries**, accepting deposits of pre-existing real resources from savers and lending them to borrowers. In financial frictions DSGEs, the **monetary side of the economy is fully determined in the real sphere** and savings need time to be accumulated through the production of additional goods.

Inside money

In reality **banks do not intermediate**, but rather create additional means of payment ex-novo by granting loans to non-bank customers. Every new loan recorded on the asset side of the bank's balance sheet is immediately offset by a matching liability in the form of a new deposit, so that the loan creation process corresponds to an expansion of the bank's balance sheet. Implications:

- since financing allows investment projects to be carried out, the national account identity between investment and savings implies that **lending is a pre-condition for savings**, rather than a consequence.
- as long as banks are free to create claims which are universally accepted as means of payment, their **credit creation potential does not find any upper bound in the amount of savings available in the economy**. The only limit is their own assessment of the implications of new lending for their profitability and solvency.

Outside money I

DSGE models assume that the **stock of legal money is either fixed and pre-existent**, or that the CB exogenously sets the growth rate of real money balances without explanation of the channels by which they are injected and distributed across agents.

In reality, two fundamental channels: 1) **cash advances** granted on demand by the Central Bank to banks, at the Central Bank policy rate. Since banks' demand for cash advances is determined in relation to the stock of deposits they hold, this channel fundamentally reflects the endogenous dynamics of loans and (matching) deposits. 2) **government's payments** and transfers to the private sector (fiscal policy) increasing agents' deposits and banks' reserves.

Conversely, legal money is destroyed whenever a private sector agent makes a payment to the government. Legal money must be already available when making these payments: **government spending must**

Outside money II

logically come before government financing and not the other way round as postulated by standard macroeconomics.

In a **closed economy money held in the private sector should be exactly equal to the amount of government bonds purchased by the CB**, which provides safe and cheap liquid assets to financial operators which can be used as a buffer stocks.

Failing to understand the endogenous nature of bank money leads to **underestimate the sources of financial instability** and the consequences of shocks hitting the banking sector. [Benes et al., 2014]

Failing to understand the nature and functioning of outside money leads to logically **inconsistent conclusions about fiscal and macro-prudential policies**.

SFC models can help to provide a fully integrated picture of the real and financial economy, tackling the endogenous nature of money.

Integrating financial and real economy

Nobody saw it coming? Not true...

Someone anticipated the crisis with remarkable precision regarding the timing and the mechanism of the collapse using a flow-of-funds approach [Godley, 1999, Godley and Wray, 1999, Godley and Zezza, 2006].

SFC modelling

The so-called "flow of funds", or "accounting", "balance sheet" approach is at the base of Post-Keynesian Stock Flow Consistent (SFC) models, whose fundamental features were defined in Godley and Lavoie [2007].

Outline

The problem of aggregation

Microeconomics vs Macroeconomics

This conceptual divide is usually associated in textbooks to the different viewpoints from which the economy is looked at.

- **micr**o: how individual consumers, workers and firms behave;
- **macro**: deals with industry/national totals and, in doing that, any distinction among different goods, markets and agents is simply ignored.

Neoclassicals argued this **dichotomy had to be eliminated** (just "Economics"). This purpose was realized with Lucas' revolution and the representative agent diffusion.

Representative Agents - Origins I

"Economists study the actions of individuals, but study them in relation to social rather than individual life"

Principles of Economics, A. Marshall.

Representative Agents - Origins II

The origin of the *Representative Agent* (RA)

Nevertheless...the 1st enunciation of the RA concept found in Marshall's *Principles*: the *representative firm*

His problem was to build a supply curve relating prices and quantities offered on the market.

- He believe that the supply depended on the production costs of firms.
- But in the markets firms have different cost structures.
- Hence, which cost must we take as a benchmark to build the supply curve?

Marshall conceived the representative firms as a sort of *average* firm which allowed to abstract from the diversity of firms' cost structure without having to assume perfect homogeneity.

Firms may have positive/negative profits: on average the representative firm sells its output at normal production costs, thus earning 0 profits.

The modern concept of RA

The **modern concept of representative agent** however stems from 2 kinds of consideration:

- *The Walrasian pursuit for* **"pure" analytical economic models**. The RA as an expedient...
  a) to abstract from firms variety and **recover analytical tractability**;
  b) to **analyze the social planner decision process** and assess economic policies desirability **in light of the Welfare Economics theorems**. To maximize welfare we have simply to maximize the RA's utility.
- **Lucas' critique**: Economic actors' behavior is not policy invariant $\rightarrow$ we must rely on **deep parameters** (preferences, technology and resources constraints): **Reductionist microfoundation based on RA to solve the trade off micro-macro coherence vs tractability.**

Lucas' critique

Lucas stated it was wrong to predict the effects of a change in economic policy entirely on the basis of relationships observed in historical aggregated data, as it was usually done in large-scale macro-econometric models:

"Given that the structure of an 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**." (Lucas, 1976, p.41)

Old (Keynesian) models parameters allegedly could not be considered as structural in the sense of **being invariant with respect to changes in government policy** variables (e.g. the Keynesian consumption function $C = \alpha + \beta Y$)
Therefore, we should **"micro-found models"** starting from the **"deep parameters"** (policy invariant) (such as preferences and technology parameters) governing individual behavior.

RA: implicit hypothesis

For Lucas' story to hold the following **assumptions** are required:

- All agents homogeneous
- No direct interaction among agents;
- No feedbacks between macro and micro (actually they are the same)
- Maximizing behavior
- Invariance of the objective function parameters;

Other common features of models with RA: rational expectations, olympic rationality, no memory and computational bounds etc.

Reductionist microfoundation: the **whole is simply the sum of its constituent parts**. You can directly infer the properties of a system by looking at the single units.

Micro-foundation through RAs

DSGE modellers thus insist that policy invariant micro-foundations are essential tools in the modelling process due to Lucas critique.

The models rely on extremely unrealistic micro-foundations, but this is not a problem per se, as **Friedmanite instrumentalism** welcomes such unrealistic foundations. This strongly instrumentalist approach makes the **DSGE modelling process simply "curve fitting"** using a certain framework.

However, the highly non-realistic hypothesis underlying these micro-foundation leads to misrepresentation of the **causes and dynamics** of economic cycles, even when models fit past data (i.e. even in "normal times").

Non-realistic micro-foundations cannot provide an adequate tool for policy analysis, especially when one also considers **how** high economic growth is achieved for instance rather than merely achieving high growth.

Aggregation, the *Fallacy of Composition/Division*, and emergence

Aggregation is where *"emergence"* enters the drama.

The physics taught us that to consider the whole as something more than its constitutive parts is a physical phenomenon, not only a theory.

Empirical evidence, as well as experimental tests, shows that aggregation generates regularities: simple and not hyper-rational individual rules when aggregated becomes well shaped: **regularities may emerge from individual "chaos"**.

"Emergence": complex (and autonomous) behaviors shown by a system stemming from simple individual heuristics.

Agent Based Models Microfoundation

Agent based models provide an alternative way to microfound economic models based on complexity theory. **Holism** in linking micro and macro.

Complex Systems: 1st approximation (tens of definitions...)

A system is said to be complex if [Tesfatsion and Judd, 2006]:

- it is composed of interacting units;
- the behavior of each component is affected by the behavior of others;
- The systems shows "emergent properties", i.e. persistet properties deriving from local interactions taking place between agents at local level, which are not inferable by looking at the properties of its constituent units, taken alone.

Examples of complex system in biology: swarms, anthills, flocks...
Features of CAS: Limited computational capacity, agents' do not know the global state of the system, routinized, simple behaviors, no coordination, local interaction, time dynamics $\rightarrow$ global self-organized functional patterns. **Micro-macro feedbacks.**

Agent Based Models Micro-foundation

ABM

Agent Based Models (ABM) in Economics conceive the economic system as a **complex adaptive system** composed of **heterogeneous, adaptive** economic actors intertwined through an **evolving network** of **local interactions** taking place within a *well-structured space*.
These interactions concur in shaping the **emergent properties** of the system. Continuous feedbacks between micro and macro levels.

ABM thus aim at providing an alternative way to microfoundation capable of **overcoming the fallacy of composition** implicit in the reductionist approach while maintaining tractability.

This approach thus studies economic systems by reconstructing them **in vitro**, that is through laboratory experiments realized via computer simulations.
In Philosophy of Science this is called a **"generative approach"** to science.

An Example of Emergent Properties: Segregation

Schelling's Model of Segregation (1978) through cellular automata.
Assumptions:

- 2 types of agents.
- Agents are placed randomly on a lattice.
- Agents are satisfied whenever in their neighborhood live a percentage $\geq$ *threshold parameter* of people of their same type.
- If not they move towards other regions.

The emergent dynamics of the model shows segregation: agents tend to gather in groups of homogeneous agents despite agents' preference do not require segregation.
"What is instructive about the experiment is the "unraveling" process. Everybody who selects a new environment affects the environment of those he leaves and those he moves among. There is a chain reaction."
[Schelling 1978, p.151]

An Example of Emergent Properties: Segregation II

Results:

- Even low level of *threshold parameter* lead to significantly higher degrees of segregation, expressed as average percentage of similar agents in a certain neighborhood.
- Till a certain threshold value of *threshold parameter* higher parameter values associated with higher segregation.
- After that threshold, people is almost never satisfied with their neighborhood and continue to move so that the system does not reach an equilibrium and the level of segregation "dramatically" drops ("tipping point").

This examples clearly shows that micro motives are something different from macro-behaviors.

Sugarscape models

Epstein and Axtell [1996] **Sugarscape models features**: the inhabitants, the environment (a two-dimensional grid), and set of rules governing the interaction of the agents with each other and the environment.
Every cell contains different amounts of sugar to harvest. In every step agents look around, seek for sugard and choose a cell, move and metabolize.
They can leave pollution, die, reproduce, inherit sources, transfer information, trade or borrow sugar, transmit diseases depending on the specific model and scenario.

Obviously these are just the ancestors of AB modelling. Now we have **large scale AB macro models** involving several markets and many types of real and financial interactions, with sophisticated rules and structures, and able to replicate a number of stylized facts.

ABM - Fundamental features

Despite many definitions of ABMs do exist, Esptein [2006] identified basic features common to most the AB literature:

- Heterogeneity
- Autonomy
- Space and Local Interactions
- Bounded/Procedural Rationality
- Focus on Out-of-Equilibrium Dynamics
- Non-linearities

Heterogeneity

Heterogeneity is crucial in ABM. No RA.
Heterogeneity is both

a) **an a priori assumption of many (not all) ABM...**
Every agents is explicitly represented and can differ in terms of preferences, initial endowments, memory, behavioral/decision rules, localization in the space, number of links within a network of social relations etc.

b) **... and an ex-post emergent property of the system dynamics.**
Divergent behaviors and heterogeneity may emerge even within a class of identical agents as a consequence of stochastic events when path-dependency exists. In many ABM agents are allowed to change their behavior in reaction to stimulus coming from the environment (see later).

Autonomy

"An autonomous agent is a system situated within and part of an environment that **senses that environment and acts on it**, *over time, in pursuit of its own agenda and so as to effect what it senses in the future."* [Franklin, 1997]

Agents can be endowed with **different degrees of learning/adaptive capability** so that they can modify, autonomously with respect to modeler, in different ways their models for understanding the environment in which they operate in order to pursue their objectives.

Different degrees of cognitive capabilities.

Autonomy II - Learning by agents

Since Simon, Newell, Shaw's work at Carnegie Tech an increasing interest for **learning algorithm and AI** (Sante Fe Institute).
Huge variety of agents types regarding learning ability:

- **0 intelligence**: totally stochastic behavior, myopic behavior, 0 adaptivity
- **Simple evolving heuristics**, switching behaviors: *"if" condition not met "then" change strategy* . Heuristics allowed to change when the agents do not attain a *satisficing* level of some target variable (e.g. profits, revenues, capital gains etc.)
- **More complex algorithms** such as:
  - Neural Networks
  - Genetic Algorithms
  - Classifier System

Space and local interaction

Events and interactions between agents take place within an **explicit spatial structure**: a grid on which a certain resource (e.g. food, energy, natural resources, ...) is distributed/generated/regenerated (as in *sugarscape* models), an n-dimensional lattice, a space of technological opportunities, a social network (possibly evolving in discrete time), a market with certain institutional rules etc.

Whatever the kind of spatial structure used, what really matters is that it allows to define the concepts of **"local" and "neighborhood"**, thus defining the position of each agents in relation to others on the base of some relevant variable.

In most cases, like in reality, **agents** do not **interact** with the totality of other agents but **only within a certain neighborhood** of their social/spatial/economic position.

Bounded rationality

Agents are characterized by **bounded/procedural rationality**.

- Bounded computational ability
- Bounded/local/incomplete information

Agents can be **either maximizers (though not perfectly rational) or characterized by 'satisficing' behavior**.

Bounded rationality

People are not perfectly rational as demonstrated by **experimental economics** (cognitive psychology).

- Inherent **difficulty in dealing with uncertainty** and probability in a risky environment characterized by fundamental uncertainty;
- Persistent **cognitive bias** (problem framing and context affect the decision process);
- **Adaptive (trial and error) and Simple behavioral rules**: complex problem decomposition in simple tasks, heuristics (i.e. routinized rules of thumb).

Bounded rationality: an experimental example

1)Assume you have been given 1000 euros. Choose between
a1) Win 1000 with 50% probability (gain zero otherwise).
a2) Win 500 with certainty.

2) Assume you have been given 2000 euros. Choose between
a2)Loose 1000 with 50% of probability (loose zero otherwise).
b2)Loose 500 with certainty.

Bounded rationality

All cases brought the same expected payoff (1500).

Everything depends on whether your risk aversion. If you choose A1 (A2) you should have chosen B1 (B2). Majority of people answered A2 and B1. What does it tell?

- **Gains are perceived differently from losses**.
- The structure of the choice affects decision making (**framing of the problem**)
- We look at **decisions in a relative way**, i.e. comparing options locally with the nearest set of alternatives rather than considering all options.
- Difficulties in dealing with uncertainty

Preferences as well were proven not to show the "smooth" properties required by Neoclassical Theory.

Non-equilibiurm dynamics and non-linearieties I

Out-of-Equilibrium dynamics

- Non-equilibrium dynamics are of central concern to agent modelers, as are large-scale transitions, **"tipping phenomena"**, and the emergence of macroscopic regularity from decentralized local interaction.
- Rather than focusing on equilibrium states of a system, the idea is to set initial condition, let the interactions of agents drive the dynamics, and see if some equilibrium develops over time.
- A **more comprehensive economic analysis not confined to initial/final state analysis**. The advantage of focus on *process* rather than *final state* is that modeling can proceed even when equilibria are computationally not tractable or even non existent. Furthermore, it provides criteria to decide between different equilibrium states when the system shows multiple equilibria.

Non-equilibiurm dynamics and non-linearieties II

Non-linearities

Non linearities arise due to feedbacks between different tiers of the economy, cumulative processes, path dependency.
In many cases models dynamics is not ergodic: relevance of initial conditions and path dependency.

4 purposes of AB modeling (I)

Tesfatsion and Judd [2006] differentiates ABMs by their objectives:

1)Empirical understanding

Why some empirical regularities are persistent and continuously evolving in time despite the lack of a social planner?
These models try to answer by identifying the causal links rooted in the repeated interactions of agents operating in a realistic environment.
The objective is to identify through computational experiments under which conditions agents interaction gives rise to the empirical regularities observed. (generativist approach, Epstein and Axtell [1996])

2)Normative understanding

AB models used as laboratory to identify and test good social designs.
The aim is to assess whether certain economic policies, social/instiutional plans will result in a socially desirable systemic performance.
In which measure the worlds emerging from these experiments are efficient, fair, stable.

4 purposes of AB modeling (II)

3) Qualitative insight and theory generation

How can we better understand economic system through the systematic investigation of their potential behaviors under different specifications of initial conditions? Why certain regularities and not others?

4) Methodological Advancement

Every modeler must formulate theoretical propositions over the model, assess the validity of these propositions through expressively designed experiments, extrapolate and reporting the information gathered through these experiments in a clear and convincing way.
Finally he has to test the data obtained from the simulations by comparing them with empirical data.

Still a huge variety of ways to conceive, develop computer programs, validate, and present the results.

References I

J. Benes, M. Kumhof, and L. Douglas. Financial crisis in dsge models: a prototype model. *IMF Working Paper Series*, 14-57:57, 2014.

O. Blanchard, D.H. Romer, M. Spence, and J. Stiglitz, editors. *In the Wake of the Crisis: Leading Economists Reassess Economic Policy*. MIT Press , Cambridge MA, 2012.

S. Borogan Aruoba, J. Fernandez-Villaverde, and J.F. Rubio-Ramirez. Comparing solution methods for dynamic equilibrium economies. *Journal of Economic Dynamics & Control*, 30, 2006.

M.K. Brunnermeier, T.M. Eisenbach, and Y. Sannikov. Macroeconomics with financial frictions: a survey. *NBER Working Paper Series*, 18102:–, 2012.

J. Epstein and R. Axtell. *Growing Artificial Societies: Social Science from the Bottom-Up*. MIT Press and Brooking Press, Washington D.C., 1996.

References II

J. Esptein. Remarks on the Foundations of Agent-Based Generative Social Science. In L. Tesfatsion and K. Judd, editors, *Handbook of Computational Economics Vol.2*, pages 1585–1602. North Holland, Amsterdam., 2006.

S. Franklin. Autonomous agents as embodied ai. *Cybernetics and Systems: An International Journal*, 28-6:490–520, 1997.

W. Godley and M. Lavoie. *Monetary Economics An Integrated Approach to Credit, Money, Income, Production and Wealth*. Palgrave MacMillan, New York, 2007.

W Godley and L. R. Wray. Can goldilocks survive? Technical report, The Levy Economic Institute of Bard College, 1999.

W. Godley and G. Zezza. Debt and lending: A cri de coeur. Technical report, Levy Institute at Bard College, 2006.

Wynne Godley. Seven Unsustainable Processes: Medium-Term Prospects and Policies for the United States and the World. Strategic analysis, The Levy Economic Institute of Bard College, 1999.

References III

N G. Mankiw. The macroeconomist as scientist and engineer. *The Journal of Economic Perspectives*, 20-4:29–46, 2006.

V. Quadrini. Macroeconomic fluctuations. *Federal Reserve Bank of Richmond Economic Quarterly*, 97-3:209254, 2011.

J. Rubio-Ramirez and J. Fernandez-Villaverde. Estimating dynamic equilibrium economies: linear versus nonlinear likelihood. *Journal of Applied Econometrics*, 20-7:891–910, 2004.

L. Tesfatsion and K. Judd. *Handbook of Computational Economics. Volume 2: Agent-Based Computational Economics*. North Holland, Amsterdam., 2006.

R.A. Werner. Can banks individually create money out of nothing? - the theories and the empirical evidence. *International Review of Financial Analysis*, 36:1–19, 2014.

R.A. Werner. A lost century in economics: Three theories of banking and the conclusive evidence. *International Review of Financial Analysis*, forthcoming, 2015. doi: doi:10.1016/j.irfa.2015.08.014.