Complexity, Agent Based Models and Critical Mathematical Economics

Dr. Johannes Buchner (IPE Berlin)

Institute for International Political Economy Berlin
Berlin School of Economics and Law

Seminar "Complexity and the Economy"
University of Tuebingen, January 23rd, 2017

Outline

Morning:

- Simulations with NetLogo (GameofLife.netlogo)
- Introduction to Programming in "Java" with "Eclipse"
- Example: GameofLife.java

Afternoon:

- Object-Oriented Programming
- Java Macro Agent-Based (JMAB) toolkit
- Critical Mathematical Economics and the Model-Theoretic Foundations of Controversies in Economic Policy

The financial crisis and the crisis in economics

- Steve Keen: Debunking Economics (2002)
- The Financial Crisis and the Systemic Failure of Academic Economics, Dahlem Report 2008 (e.g. by Hans Foellmer)
- Adair Turner: Economics after the Crisis (2012)
- Institute for New Economic Thinking (INET, founded 2009)

Mathematics for New Economic Thinking

- MNET: Fields Institute, 2013 (organized by M. Grasselli)
- Critical Mathematical Economics: Mathematics has been partly misused in mainstream economics to justify 'unregulated markets' before the crisis
- New approaches: e.g. Systemic Risk in Banking Systems, Revival of Keynes and Minsky in Macroeconomics

Critical Mathematical Economics?

- Part A: (Mathematical) Critique of Mainstream Models (e.g. DSGE, SMD Theorems)
- Part B: Improve existing (heterodox) models with ingredients from Complexity (e.g. Dynamical Systems, ABM, Statistical Physics)
- Part C: Develop models for Policy Advice in new areas (e.g. Gender Aware Economics, Economic Democracy)

Dynamic Stochastic General Equilibrium (DSGE)

- Standard model in Macroeconomics
- Seeks to explain the aggregate economy using theories based on strong microeconomic foundations.
- Collective decisions of rational individuals over a range of variables for both present and future.
- All variables are assumed to be simultaneously in equilibrium.

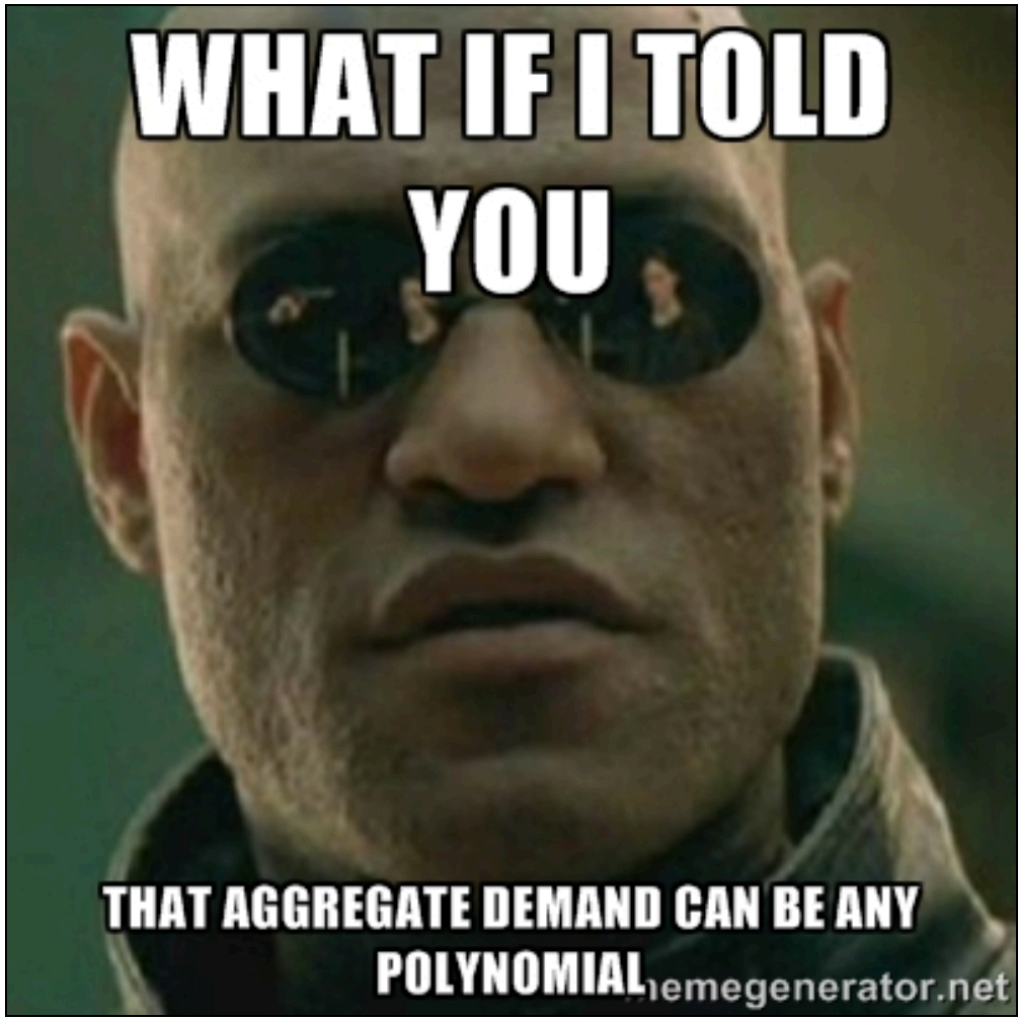
DSGE and 'General Equilibrium Theory' as a Microfoundation

Theorem (from 'The theory of general economic equilibrium: A differentiable approach'. A. Mas-Colell, 1985).

Let $z : S \to \mathbb{R}^l$ be a C^3- vector field satisfying some boundary conditions. Then for any $\epsilon > 0$ we can find an economy E such that the excess demand function of E coincides with f on S_ϵ and p is an equilibrium for E if and only if $z(p) = 0$

It is also known as 'Sonnenschein-Mantel-Debreu Theorem', or 'anything goes' Theorem.

SMD theorem: something is rotten in GE land



Alternative Microfoundations: ABMs

- 'Agent Based Models' as a Microfoundation
- simulate the behaviour of heterogenous agents on the computer numerically
- Reference: e.g. 'Handbook of Computational Economics' (Volumes 1-3, most recent 2014)
- sometimes critized as 'black box', as until recently no analytical solutions had been available
- Idea: Use methods from statistical physics to provide those by a mean-field approximation (see e.g. S. Landini, 2014)

A probabilistic Micro-/Mesofoundation of Macroeconomics

'The point is that precise behavior of each agent is irrelevant. Rather we need to recognize that microeconomic behavior is fundamentally stochastic.' (Aoki and Yoshikawa 2006)

Idea:

- identifying homogeneous sub-populations of agents
- computing the mean-field variables (mean-field approximation), on an intermediate 'Meso-level'
- master equation: study of the dynamics of the number of agents in each cluster, i.e. the transition probabilities
- Project with M.Grasselli and Patrick Li: Link this to Stock-Flow-Consistent Maroeconomic Models

Back to Macroeconomics: Dynamic Stochastic General Equilibrium (DSGE)

- Equilibrium is only disrupted by exogenous shocks.
- The only way the economy can be in disequilibrium at any point in time is through decisions based on wrong information
- Money is neutral in its effect on real variables.
- Neoclassical economics is based on barter paradigm: money is convenient to eliminate the double coincidence of wants. DSGE is 'Macroeconomics without banks'!

Minsky's alternative interpretation of Keynes

- In a modern economy, financial institutions determine the way funds are available for ownership of capital and production.
- Economy is fundamentally cyclical, with each state (boom, crisis, deflation, stagnation, expansion and recovery) containing the elements leading to the next in an identifiable manner.
- "Stability - or tranquility -is destabilizing" (in a world with a cyclical past and capitalist financial institutions).

Minsky's Financial Instability Hypothesis

- Start when the economy is doing well but firms and banks are conservative. Most projects succeed -it pays to lever.
- Beginning of "euphoric economy": increased debt to equity ratios, development of Ponzi/Speculative financier.
- Viability of business activity is eventually compromised.
- Ponzi financiers have to sell assets, liquidity dries out, asset market is flooded. Euphoria becomes a panic.

Stock-Flow Consistent models

- Stock-flow consistent models emerged in the last decade as a common language for many heterodox schools of thought in economics.
- They consider both real and monetary factors simultaneously.
- Specify the balance sheet and transactions between sectors.
- Reject the RARE individual (representative agent with rational expectations) in favour of SAFE (sectoral average with flexible expectations) modelling.
- See Godley and Lavoie (2007) for the full framework.

Goodwin Model - SFC matrix

Balance Sheet	Households	Firms		Sum
		current	capital	
Capital			$+pK$	pK
Sum (net worth)	0	0	V_f	pK
Transactions				
Consumption	$-pC$	$+pC$		0
Investment		$+pI$	$-pI$	0
Acct memo [GDP]		$[pY]$		
Wages	$+W$	$-W$		0
Profits		$-\Pi$	$+\Pi_u$	0
Sum	0	0	0	0
Flow of Funds				
Capital			$+pI$	pI
Sum	0	0	Π_u	pI
Change in Net Worth	0	$pI + \dot{p}K - p\delta K$		$\dot{p}K + p\dot{K}$

Table: SFC table for the Goodwin model.

Goodwin Model (1967) - Assumptions

- Assume that

$$N(t) = N_0 e^{\beta t} \quad \text{(total labour force)}$$
$$a(t) = a_0 e^{\alpha t} \quad \text{(productivity per worker)}$$
$$Y(t) = \nu K(t) = a(t)L(t) \quad \text{(total yearly output)}$$

  where K is the total stock of capital and L is the employed population.

- Assume further that

$$\dot{\mathrm{w}} = \Phi(\lambda)\mathrm{w} \quad \text{(Phillips curve)}$$
$$\dot{K} = (Y - \mathrm{w}L) - \delta K \quad \text{(Say's Law)}$$

Goodwin Model - Differential equations

- Define

$$\omega = \frac{\mathrm{w}L}{Y} = \frac{\mathrm{w}}{a} \quad \text{(wage share)}$$

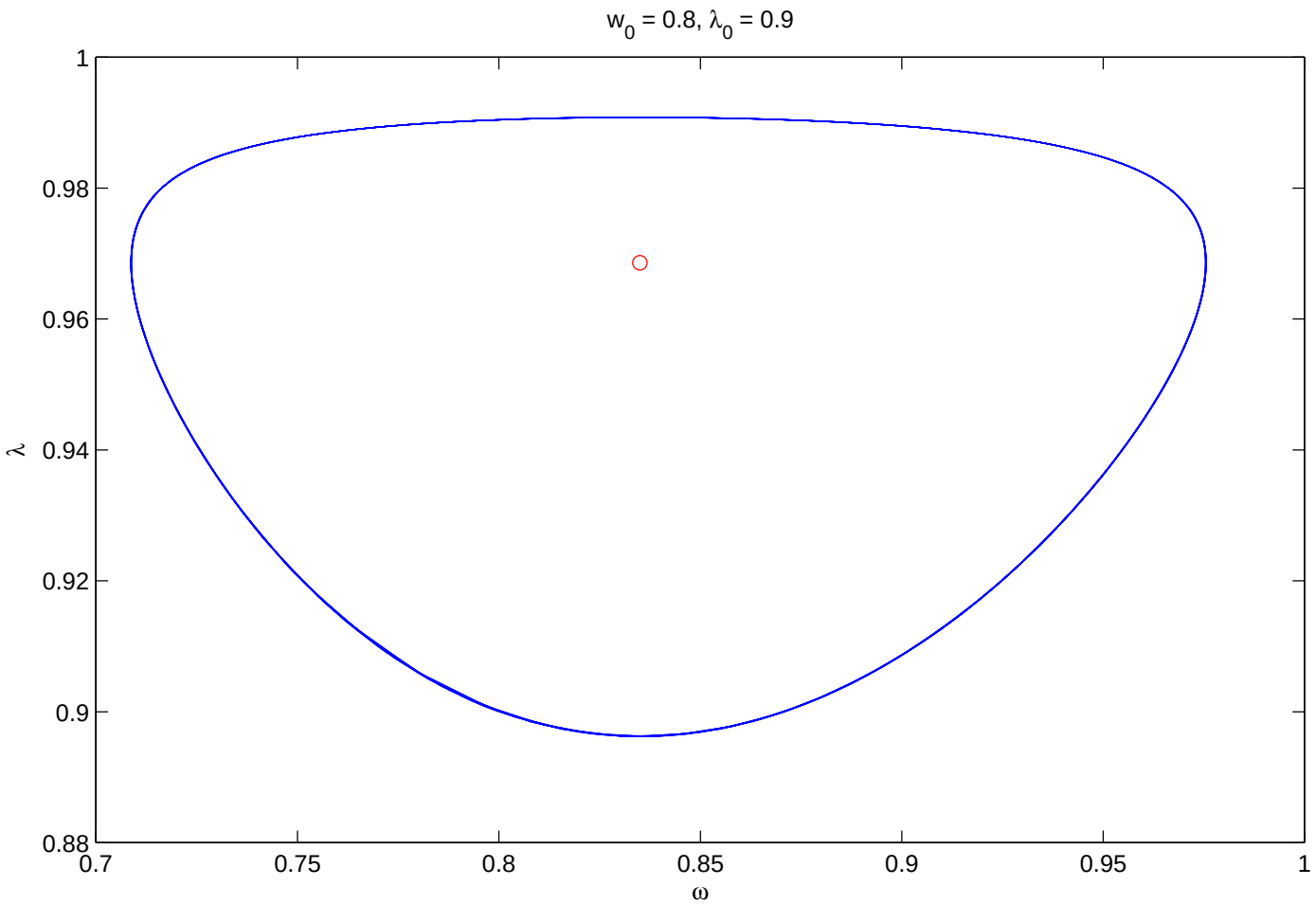
$$\lambda = \frac{L}{N} = \frac{Y}{aN} \quad \text{(employment rate)}$$

- It then follows that

$$\dot{\omega} = \omega(\Phi(\lambda) - \alpha)$$

$$\dot{\lambda} = \lambda\left(\frac{1-\omega}{\nu} - \alpha - \beta - \delta\right)$$

Example: Goodwin model



SFC table for Keen (1995) model

Balance Sheet	Households	Firms		Banks	Sum
		current	capital		
Deposits	$+D$			$-D$	0
Loans			$-L$	$+L$	0
Capital			$+pK$		pK
Sum (net worth)	V_h	0	V_f	0	pK
Transactions					
Consumption	$-pC$	$+pC$			0
Investment		$+pI$	$-pI$		0
Acct memo [GDP]		$[pY]$			
Wages	$+W$	$-W$			0
Interest on deposits	$+rD$			$-rD$	0
Interest on loans		$-rL$		$+rL$	0
Profits		$-\Pi$	$+\Pi_u$		0
Sum	S_h	0	$S_f - pI$	0	0
Flow of Funds					
Deposits	$+\dot{D}$			$-\dot{D}$	0
Loans			$-\dot{L}$	$+\dot{L}$	0
Capital			$+pI$		pI
Sum	S_h	0	Π_u	0	pI
Change in Net Worth	S_h	$(S_f + \dot{p}K - p\delta K)$			$\dot{p}K + p\dot{K}$

Table: SFC table for the Keen model.

Keen model - allow Investment through debt

- Assume now that new investment is given by

$$\dot{K} = \kappa(\pi)Y - \delta K$$

where $\kappa(\cdot)$ is a nonlinear increasing function of profits $\pi = 1 - \omega - rd$.

- This leads to external financing through debt evolving according to

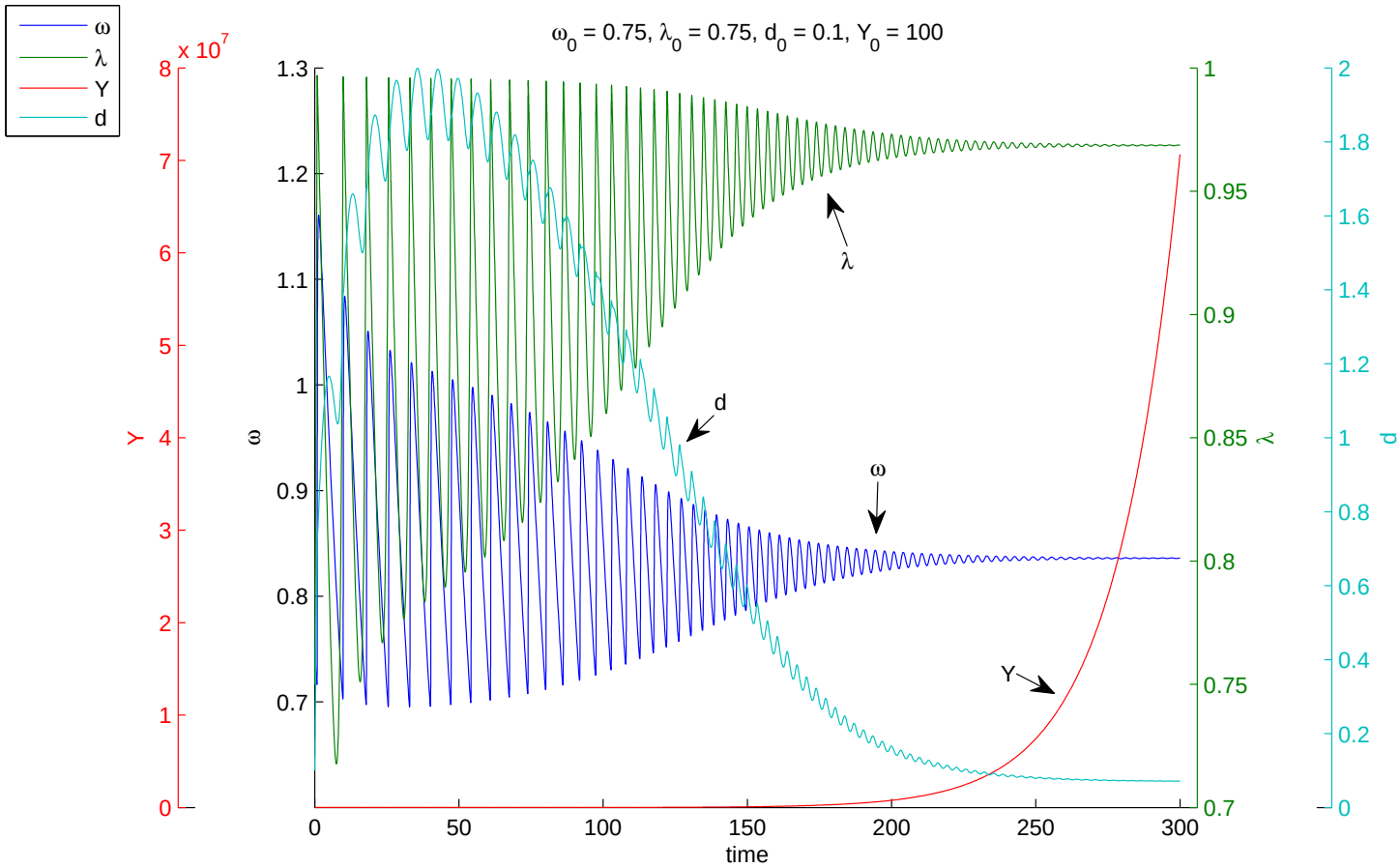
$$\dot{D} = \kappa(\pi)Y - \pi Y$$

Keen model - Differential Equations

Denote the debt ratio in the economy by $d = D/Y$, the model can now be described by the following system

$$\dot{\omega} = \omega \left[\Phi(\lambda) - \alpha\right]$$
$$\dot{\lambda} = \lambda \left[g(\pi) - \alpha - \beta\right]$$
$$\dot{d} = \kappa(\pi) - \pi - dg(\pi)$$

Example: convergence to the good equilibrium in a Keen model



Example: explosive debt in a Keen model

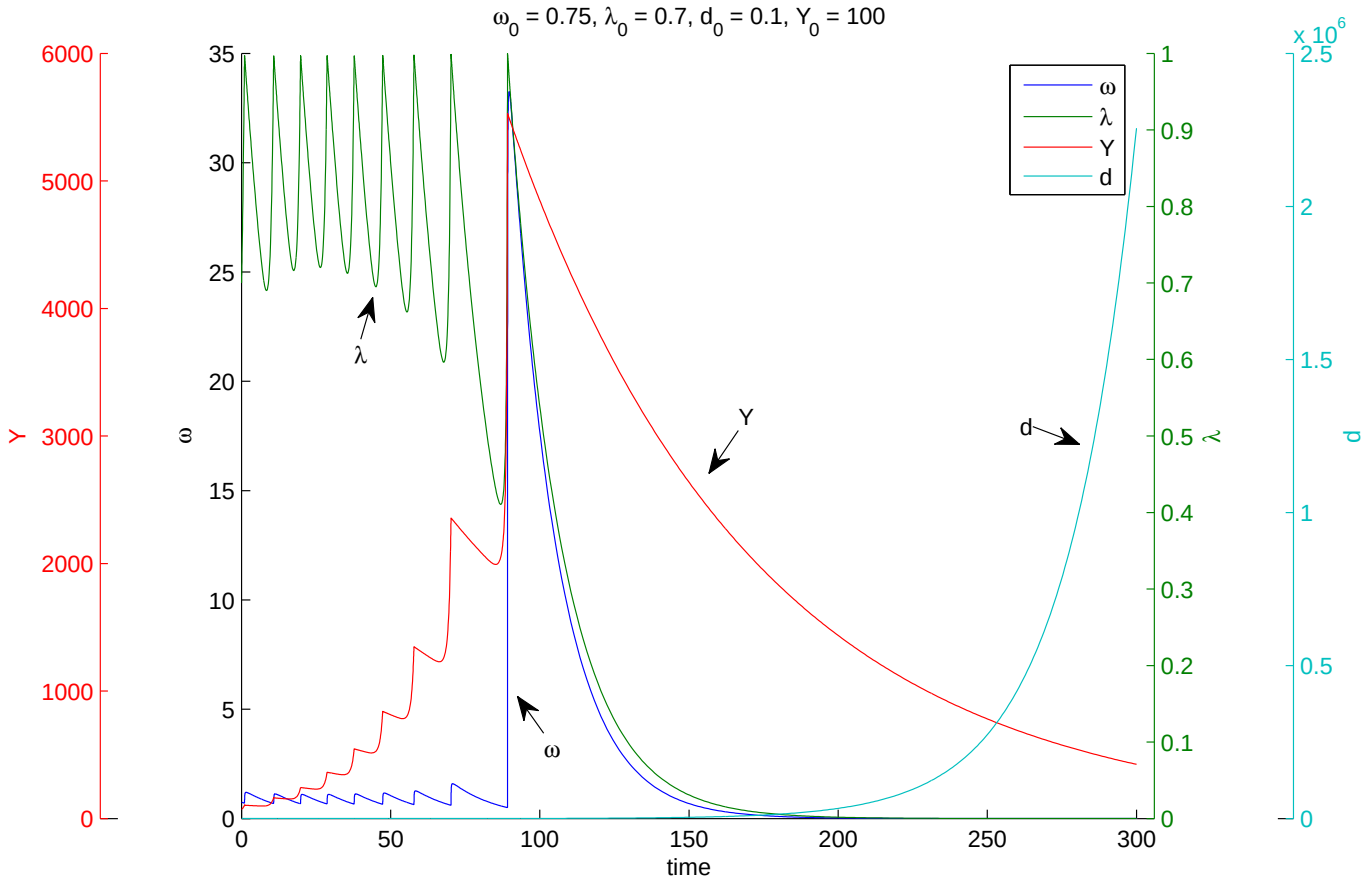
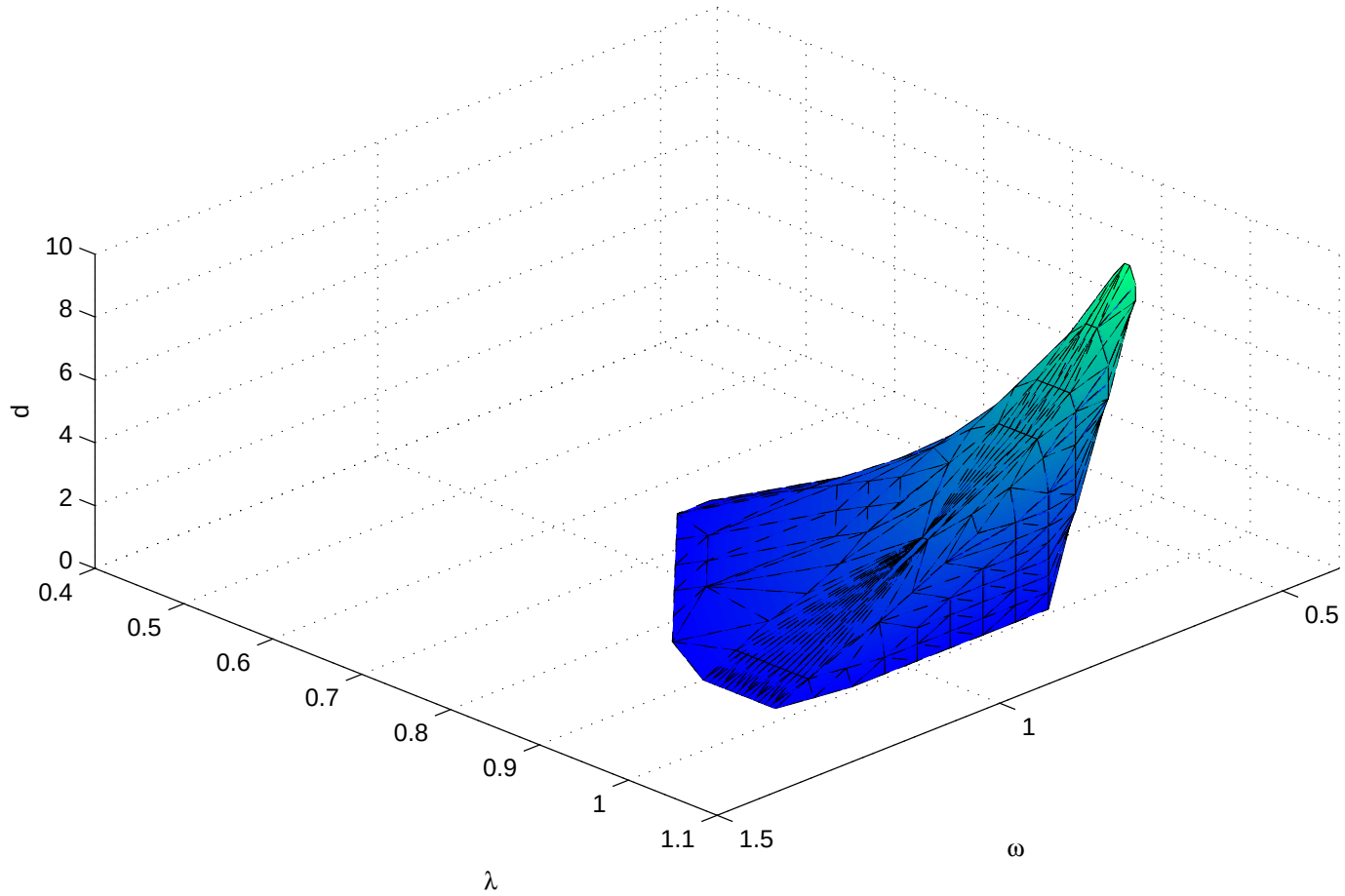


Figure: Grasselli and Costa Lima (2012)

Basin of convergence for Keen model



Ponzi financing

To introduce the destabilizing effect of purely speculative investment, we consider a modified version of the previous model with

$$\dot{D} = \kappa(1 - \omega - rd)Y - (1 - \omega - rd)Y + P$$
$$\dot{P} = \Psi(g(\omega, d)P$$

where P stands for Ponzi (speculative) financing and $\Psi(\cdot)$ is an increasing function of the growth rate of economic output.

Example: Destabilizing effect of Ponzi financing

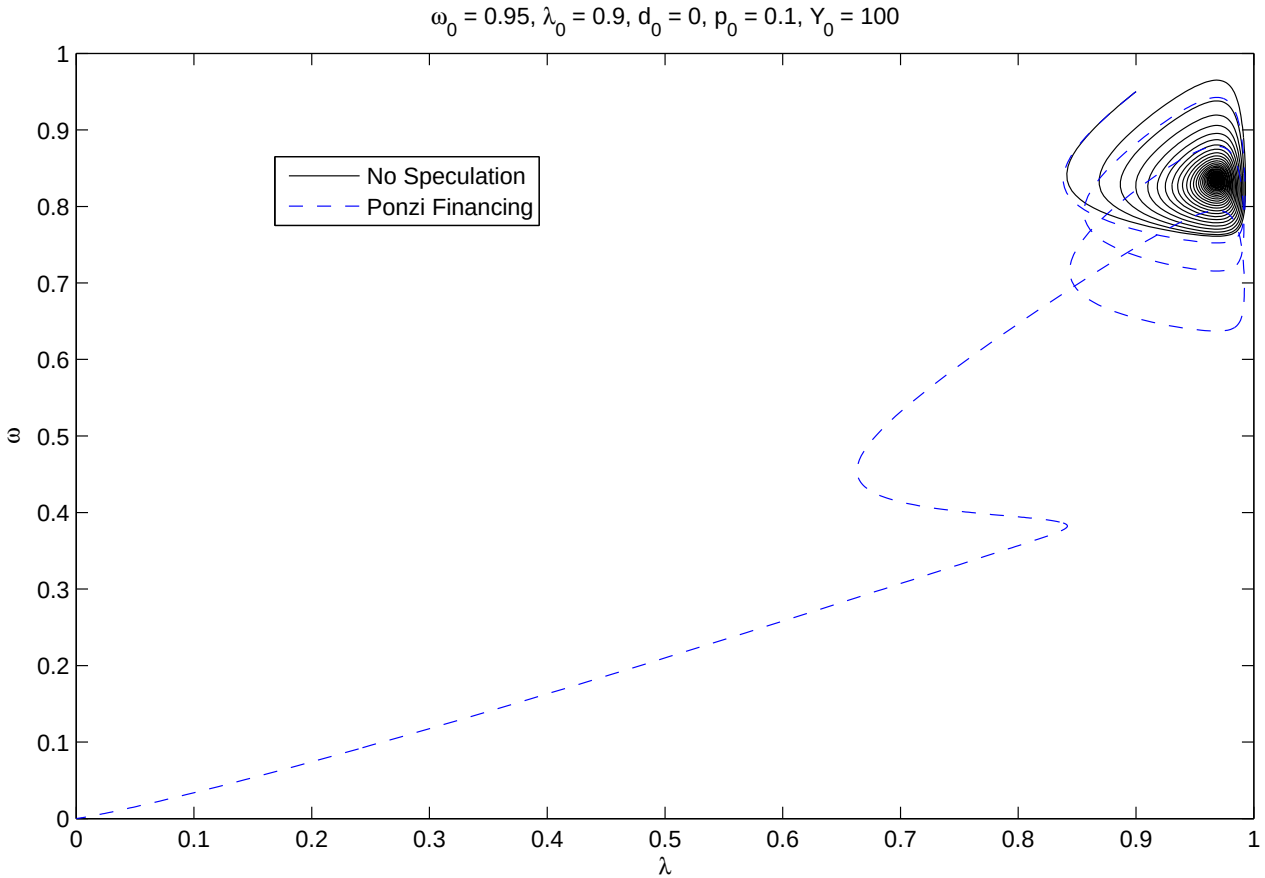


Figure: Grasselli and Costa Lima (2012)

The Great Moderation in the U.S. - 1984 to 2007

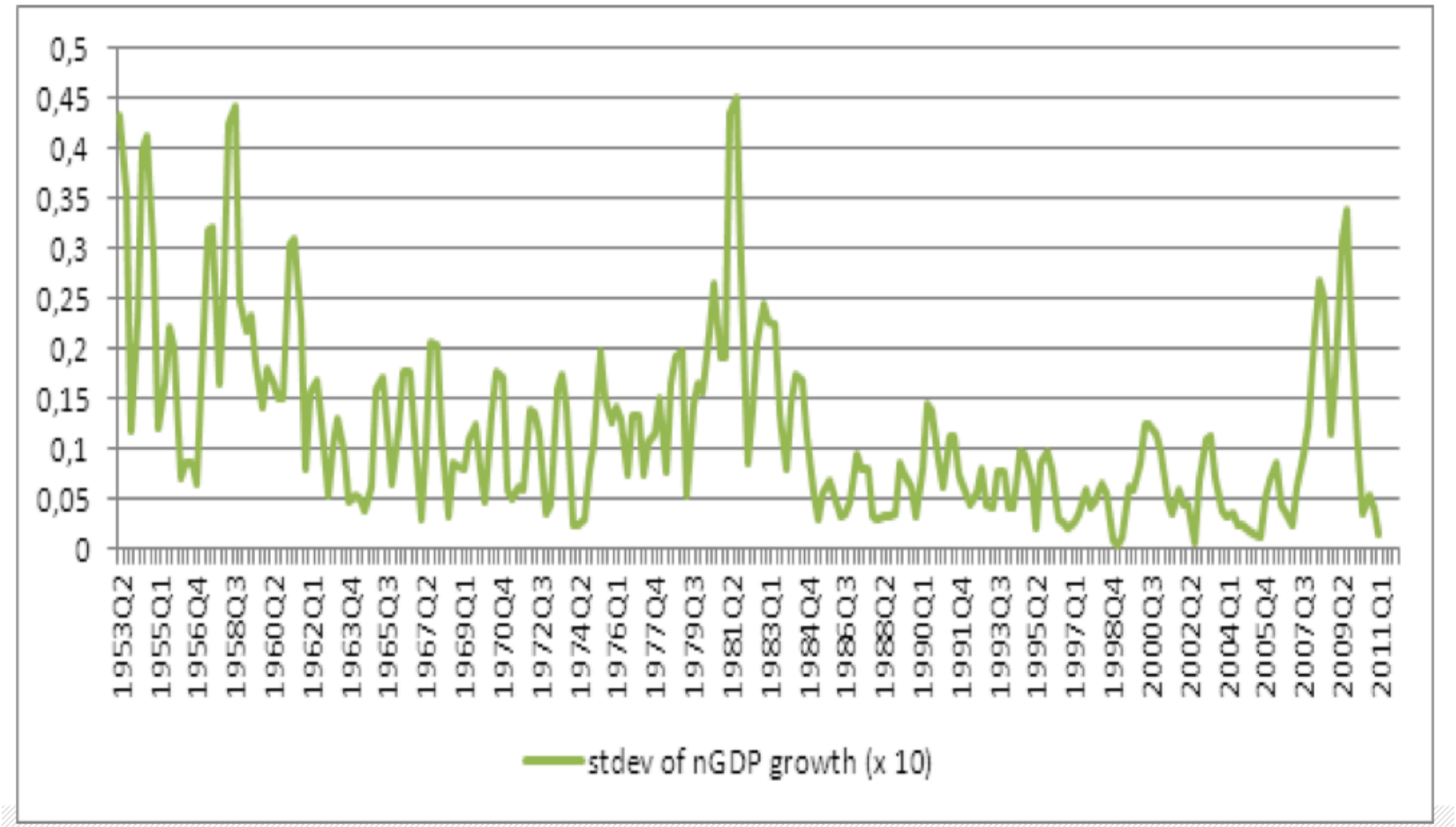


Figure: Grydaki and Bezemer (2013)

Possible explanations

- Real-sector causes: inventory management, labour market changes, etc.
- Financial-sector causes: financial innovation, deregulation, better monetary policy, etc.
- Grydaki and Bezemer (2013): growth of debt in the real sector.

Bank credit-to-GDP ratio in the U.S

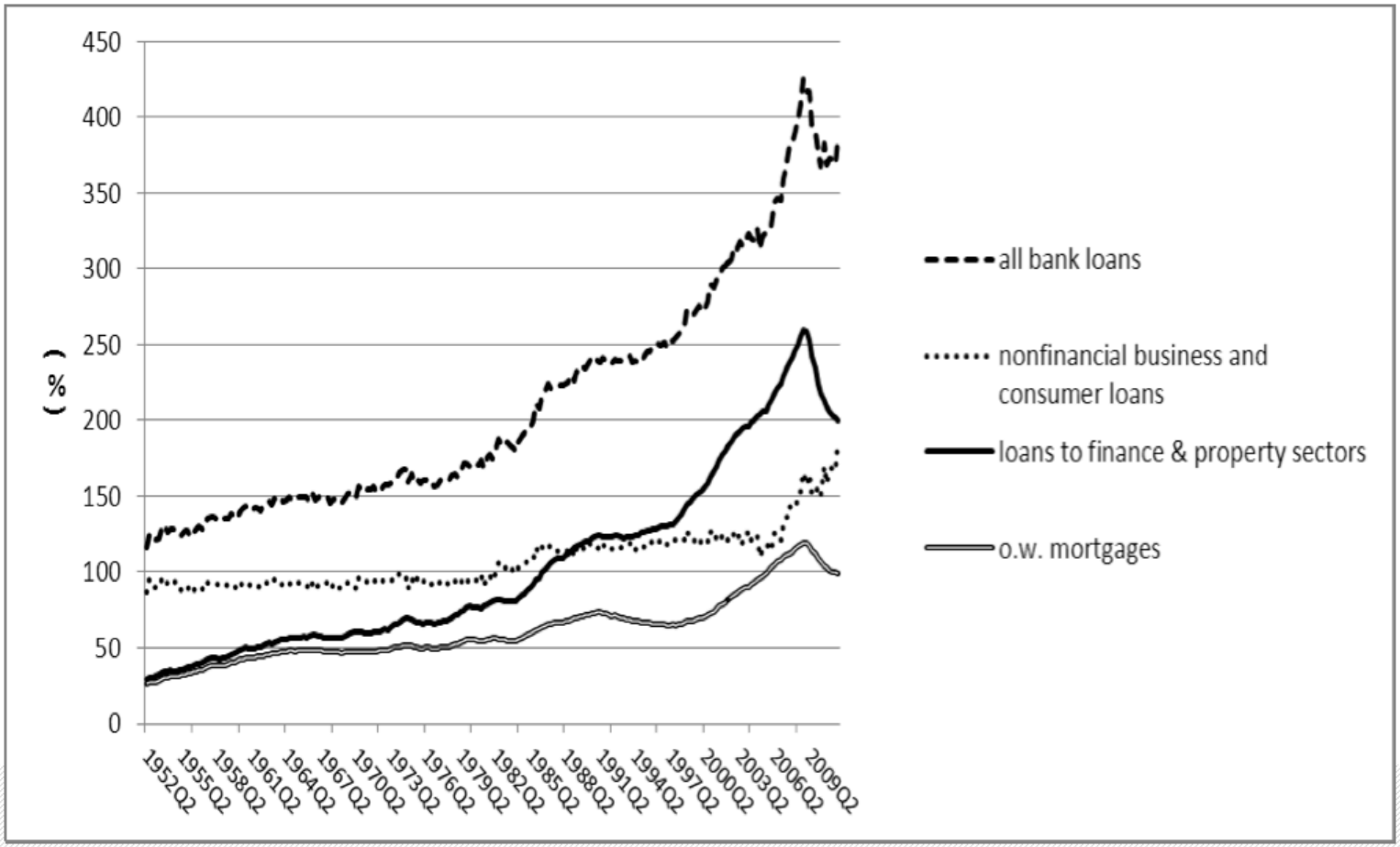
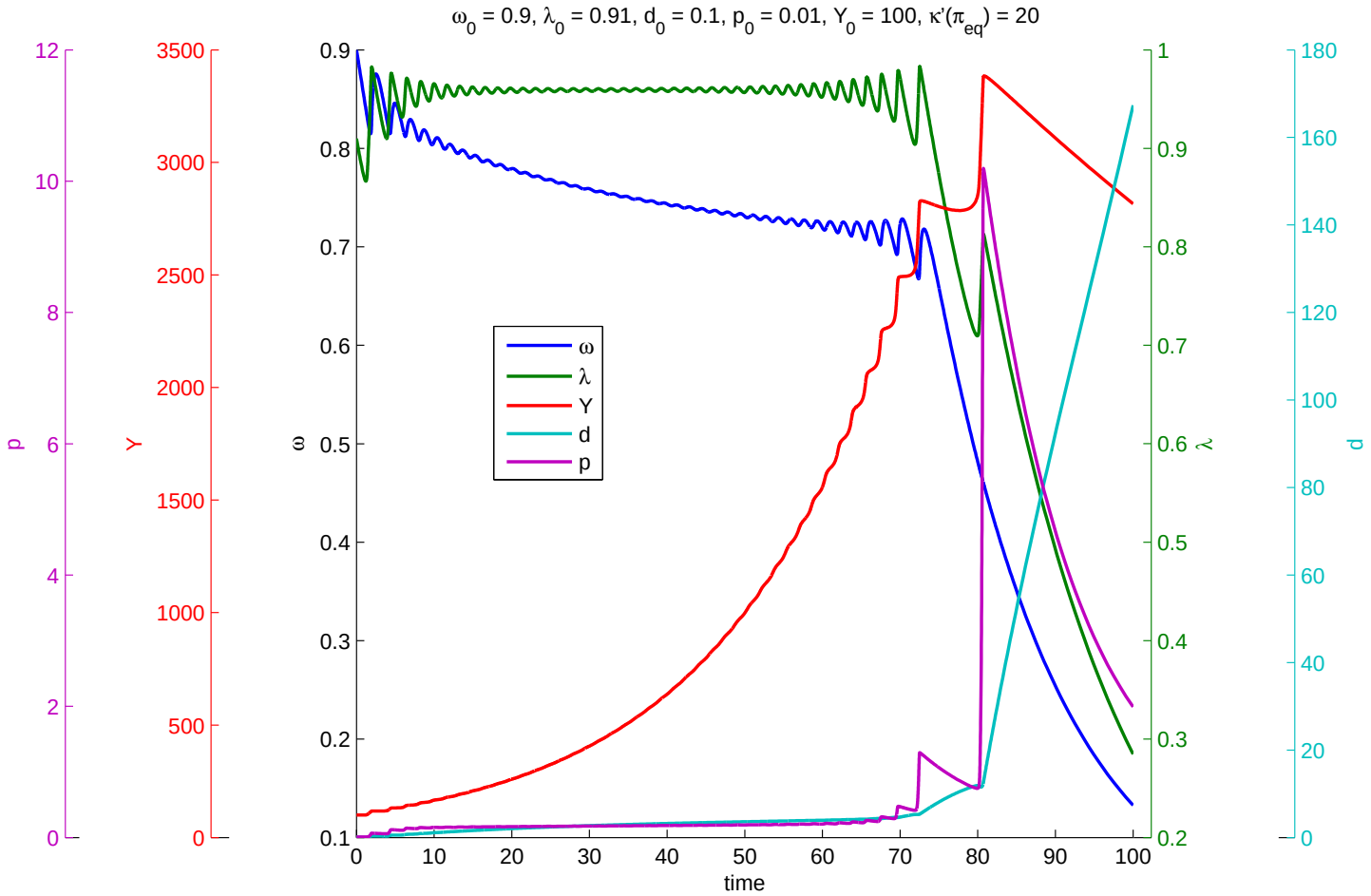


Figure: Grydaki and Bezemer (2013)

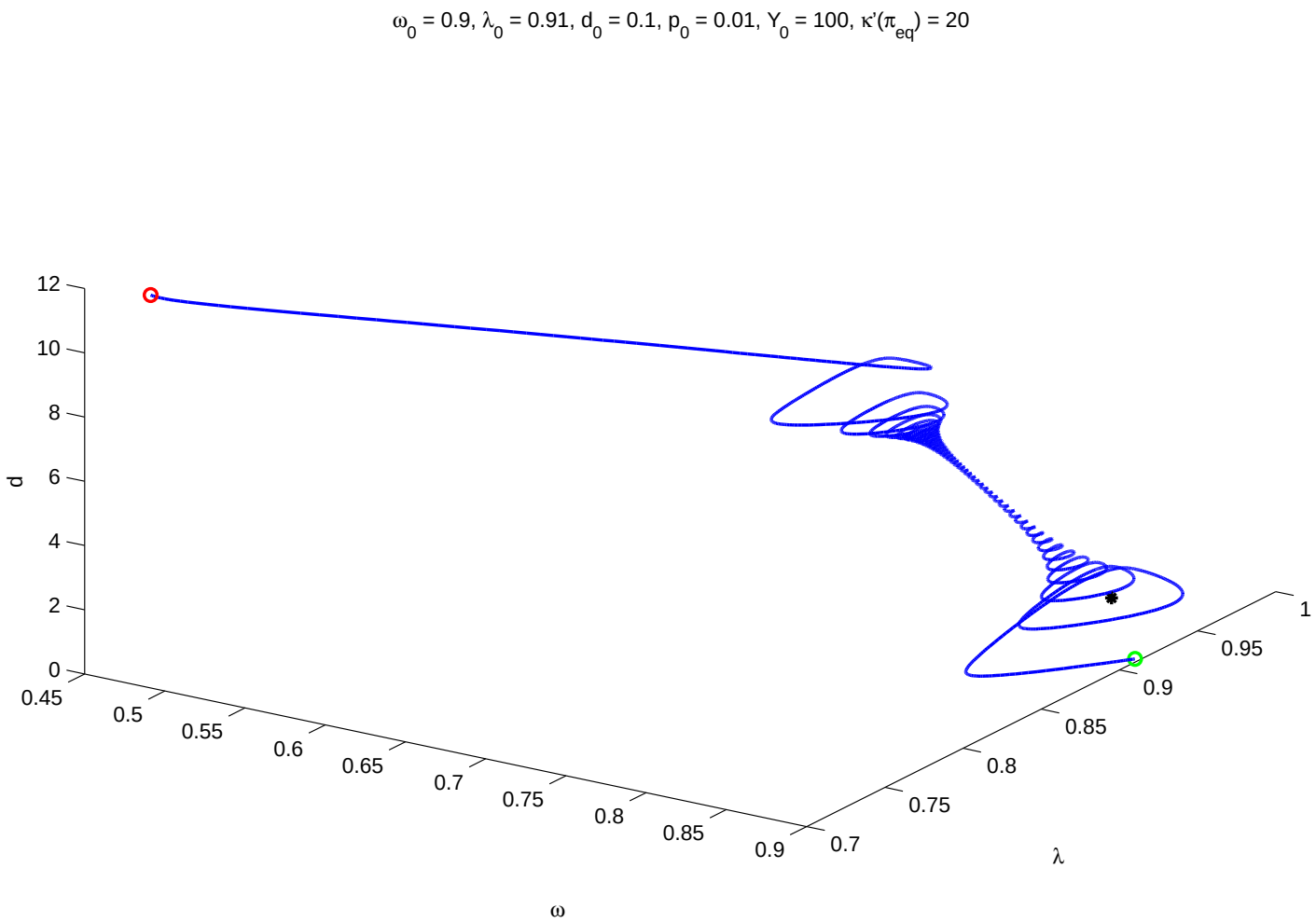
Modelling the Great Moderation: Keen model with Ponzi financing

- Story: high debt $\rightarrow$ growth with low volatility $\rightarrow$ even higher debt $\rightarrow$ explosive volatility
- Idea: choose initial conditions that are close to the basin of attraction of the equilibrium point with finite debt, but not inside it
- Result: long period of very low volatility, followed by explosion and collapse

Example: strongly moderated oscillations



Example (cont): Shilnikov bifurcation



Pseudo-Cycles and wage-led vs. profit-led

- Goodwin / Keen models: 'profit-led' or 'investment-driven' (investment is modelled, depends positively on profits, and consumption adjusts)
- Debt-Dynamics model: 'wage-led' or 'consumption-driven' (consumption is modelled, depends positively on wages, and investment adjusts)
- Research Question: Could there be a model that 'looks like' profit-led (e.g. by showing Goodwin-Cycles), but it is indeed wage-led?
- Joint with Charlie Brummit (Columbia), Torsten Heinrich (Bremen), Engelbert Stockhammer (Kingston)

A simplified 'toy' Goodwin Model

We follow [Stockhammer, Mitchel 2014]. They consider the following 'toy' Goodwin model

$$\dot{y} = y(1 - w)$$
$$\dot{w} = w(-c + ry)$$

Note: This corresponds to the Goodwin model discussed above with parameters $\alpha = \beta = \delta = 0$ and $\nu = 1$, where we have chosen a linear Phillips curve $\Phi(\lambda) = -c + r\lambda$

Example: 'Goodwin Cycles'

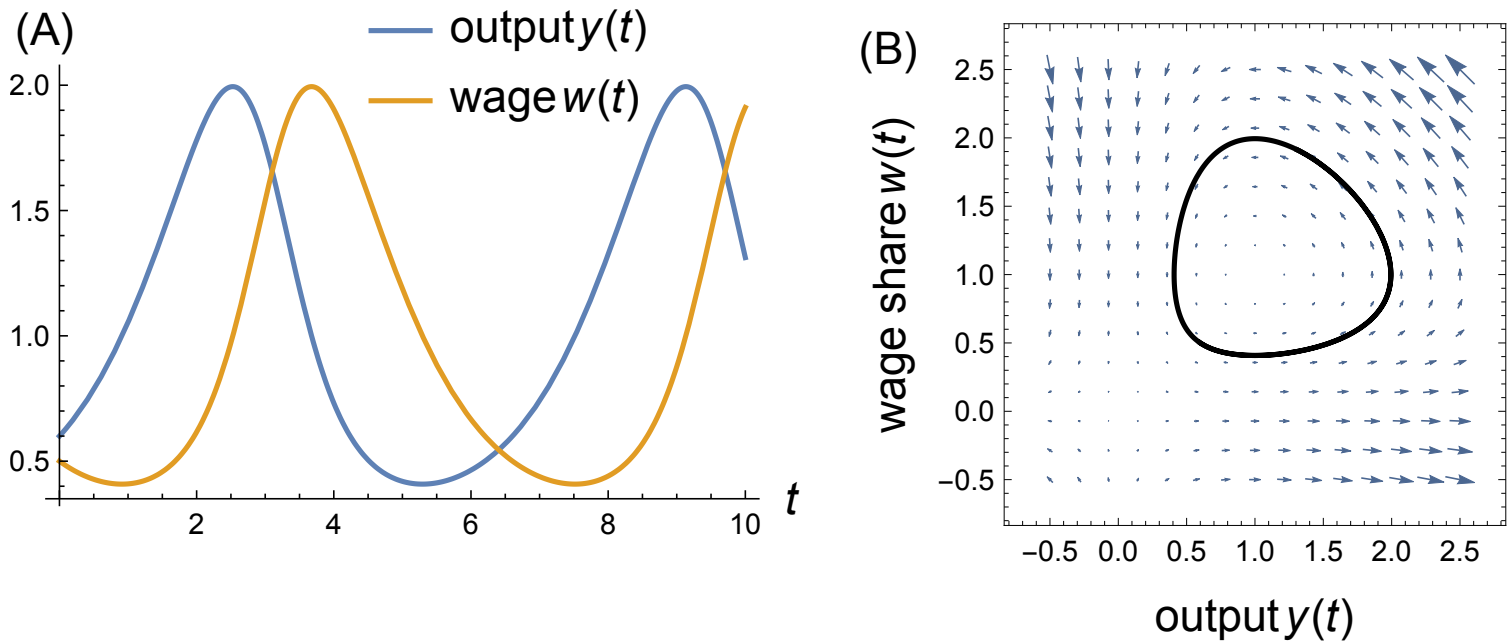


Figure: Sample orbit of the toy Goodwin model for $r = c = 1$ and initial condition $y(0) = 0.6, w(0) = 0.5$.

Recall: Minsky's FIH - a Minsky Cycle

- Start when the economy is doing well but firms and banks are conservative. Most projects succeed -it pays to lever.
- Beginning of "euphoric economy": increased debt to equity ratios, development of Ponzi/Speculative financier.
- Viability of business activity is eventually compromised.
- Ponzi financiers have to sell assets, liquidity dries out, asset market is flooded. Euphoria becomes a panic.

A toy 2d Minsky Model

Let's consider the following ' toy Minsky Model' model

$$\dot{y} = y(1 - f) \tag{1}$$

$$\dot{f} = f(-1 + py) \tag{2}$$

Note: f stands for 'financial fragility' (think debt), and plays the role of the wage-share in the Goodwin model (the model above is equivalent to the toy Goodwin model for c=1, w=f, and renaming r to p)

Example: 'Minsky Cycles'

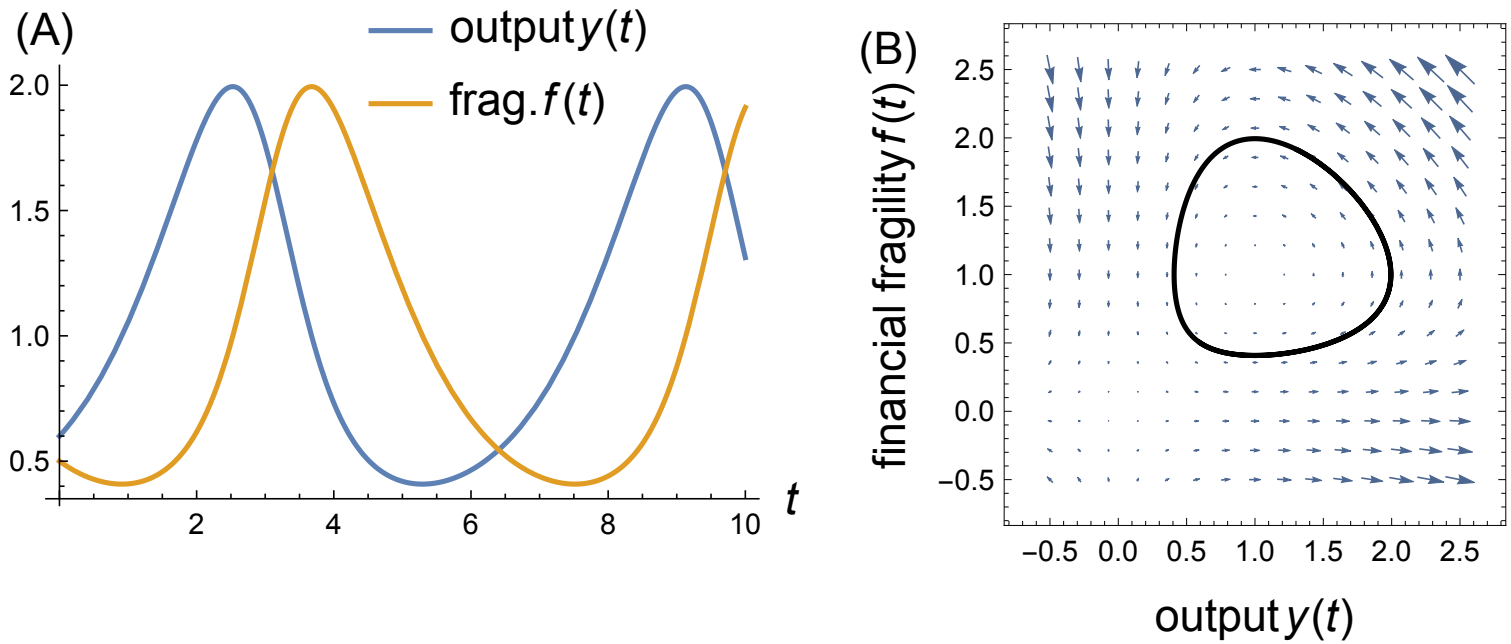


Figure: Sample orbit of the 2d Minsky model showing a 'Minsky Cycle' (for $p = 1$ and initial condition $y(0) = 0.6, f(0) = 0.5$).

A 3d Minsky Model with wage share

Finally, consider the following 3d Minsky Model, by adding a wage share variable (3) to equations (1) and (2):

$$\begin{aligned} \dot{y} &= y(1-f) \\ \dot{f} &= f(-1+py) \\ \dot{w} &= w(-c+ry-w) \end{aligned} \tag{3}$$

A *pseudo-Goodwin cycle* is a counterclockwise closed orbit in $(y(t), w(t))$ such that y and w form a master-slave system (i.e. there is a feedback from y to w, but not vice-versa).

Example: 'Pseudo Goodwin Cycles'

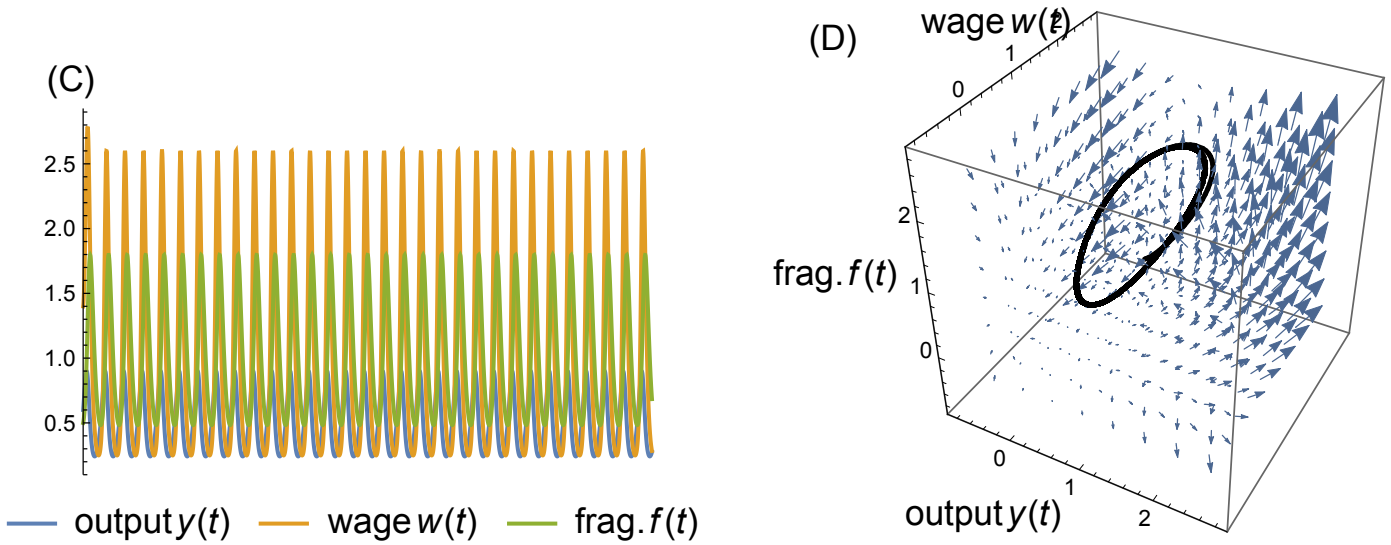


Figure: Sample orbit in 3d Minsky model: 'Pseudo Goodwin Cycle' (for $p = 2, r = 5, c = 3/2$ and $y(0) = 0.6, f(0) = 0.5, w(0) = 0.4$).

General Pseudo-Cycles

- Goal 1: Try to find Pseudo Goodwin Cycles in a wage-led Minsky model and make it rigorous
- Goal 2: Generalize the 'Pseudo-Cycles' idea and relate to discussion on observational equivalence
- Note: Discussion if economy is profit-led' or 'wage-led' is very relevant for economic policy!

Concluding remarks

- We discussed stock-flow macro-models and their micro-/meso-foundations.
- Applications included modelling the Great Moderation and the identification of Pseudo-Cycles
- The modelling framework is an alternative to the dominant microfounded DSGE paradigm in macroeconomics.
- Our approach opens up new avenues for the application of modern mathematical techniques to economics

Promising Areas of Cooperation

- Hysteresis - Post-Keynesian Labour Market
- Networks Systemic Risk (e.g. Book by Tom Hurd)
- Mean Field Games and applications in economics
- Maybe even Turing instability, Delayed Feedback Control ...

New collaborators welcome - please check my homepage for updates (hint: google Critical Mathematical Economics :)

Outlook

- Complexity and the Art of Public Policy (Colander, 2014):
- 'Complexity science is changing the way we think about social systems and social theory'
- Necessary to combine advanced technical methods with a critical view towards economic theory, largely unexplored field
- W. Elsner (2015): Policy Implications of Economic Complexity and Complexity Economics

Example: Workshop Complexity Economics at Fields 2016

- took place at April 26-28, 2016 at Fields Institute Toronto, Canada (www.fields.utoronto.ca/activities/15-16/complexity)
- organized by me in collaboration with Johannes Tiemer (Uni Duisburg-Essen)
- Talks by D. Colander (Middlebury College, USA) and I. Nikolic (TU Delft, Netherlands) are online!
- supported by the Young Scholars Initiative of INET

Interesting Activities 2017

Summer School on Macroeconomics Economic Policies

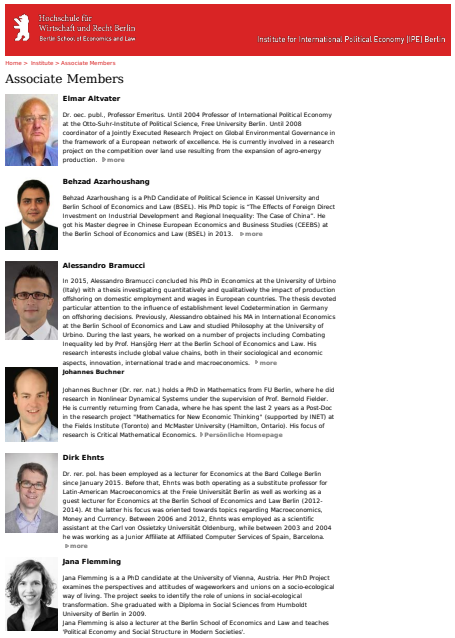
- 30.7.-5.8.2017 in Berlin, organized by IMK - Macroeconomic Policy Institute
- for graduate students (MA and PhD) and junior researchers, application deadline: 15th of March
- overview lectures on stock-flow-consistent and agent-based modelling

EAEPE Annual Conference

- 19.-21.10. 2017 in Budapest, organized EAEPE - European Association for Evolutionary Political Economy
- introductory lecture for graduate students and junior researchers
- Special Session on "Agent-based macro models and post-Keynesian economics"

IPE - Institute for International Political Economy Berlin

Model-Theoretic Foundations of Controversies in Economic Policy



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Home > Institute > Associate Members

Associate Members

Elmar Altvater

Dr. oec. publ., Professor Emeritus. Until 2004 Professor of International Political Economy at the Otto-Suhr-Institute of Political Science, Free University Berlin. Until 2008 coordinator of a Jointly Executed Research Project on Global Environmental Governance in the framework of a European network of excellence. He is currently involved in a research project on the competition over land use resulting from the expansion of agro-energy production. ▷ more

Behzad Azarhoushang

Behzad Azarhoushang is a PhD Candidate of Political Science in Kassel University and Berlin School of Economics and Law (BSEL). His PhD topic is "The Effects of Foreign Direct Investment on Industrial Development and Regional Inequality: The Case of China". He got his Master degree in Chinese European Economics and Business Studies (CEBS) at the Berlin School of Economics and Law (BSEL) in 2013. ▷ more

Alessandro Bramucci

In 2015, Alessandro Bramucci concluded his PhD in Economics at the University of Urbino (Italy) with a thesis investigating quantitatively and qualitatively the impact of production offshoring on domestic employment and wages in European countries. The thesis devoted particular attention to the influence of establishment level Codetermination in Germany on offshoring decisions. Previously, Alessandro obtained his MA in International Economics at the Berlin School of Economics and Law and studied Philosophy at the University of Urbino. During the last years, he worked on a number of projects including Combating Inequality led by Prof. Hansjörg Herr at the Berlin School of Economics and Law. His research interests include global value chains, both in their sociological and economic aspects, innovation, international trade and macroeconomics. ▷ more

Johannes Buchner

Johannes Buchner (Dr. rer. nat.) holds a PhD in Mathematics from FU Berlin, where he did research in Nonlinear Dynamical Systems under the supervision of Prof. Bernold Fiedler. He is currently returning from Canada, where he has spent the last 2 years as a Post-Doc in the research project "Mathematics for New Economic Thinking" (supported by INET) at the Fields Institute (Toronto) and McMaster University (Hamilton, Ontario). His focus of research is Critical Mathematical Economics. ▷ Persönliche Homepage

Dirk Ehnts

Dr. rer. pol. has been employed as a lecturer for Economics at the Bard College Berlin since January 2015. Before that, Ehnts was both operating as a substitute professor for Latin-American Macroeconomics at the Freie Universität Berlin as well as working as a guest lecturer for Economics at the Berlin School of Economics and Law Berlin (2012-2014). At the latter his focus was oriented towards topics regarding Macroeconomics, Money and Currency. Between 2006 and 2012, Ehnts was employed as a scientific assistant at the Carl von Ossietzky Universität Oldenburg, while between 2003 and 2004 he was working as a Junior Affiliate at Affiliated Computer Services of Spain, Barcelona. ▷ more

Jana Flemming

Jana Flemming is a a PhD candidate at the University of Vienna, Austria. Her PhD Project examines the perspectives and attitudes of wageworkers and unions on a socio-ecological way of living. The project seeks to identify the role of unions in social-ecological transformation. She graduated with a Diploma in Social Sciences from Humboldt University of Berlin in 2009.
Jana Flemming is also a lecturer at the Berlin School of Economics and Law and teaches 'Political Economy and Social Structure in Modern Societies'.

Check my website for references - Thank you for your attention!