



Agent-based modelling for macroeconomic policy design

Silvano Cincotti



CINEF
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Summary



- Economy as a complex system
- The EURACE artificial economy
- An example
- Final remarks

Explaining economic phenomena



- Everyone wants to know how the economy can suddenly go into a downturn like the current crisis
- We should build models which can explain this without *ad hoc* explanations
- We should view the economy as a “complex adaptive system” and for this we must have recourse to artificial economies offer

Complexity and the Construction of Artificial Economies



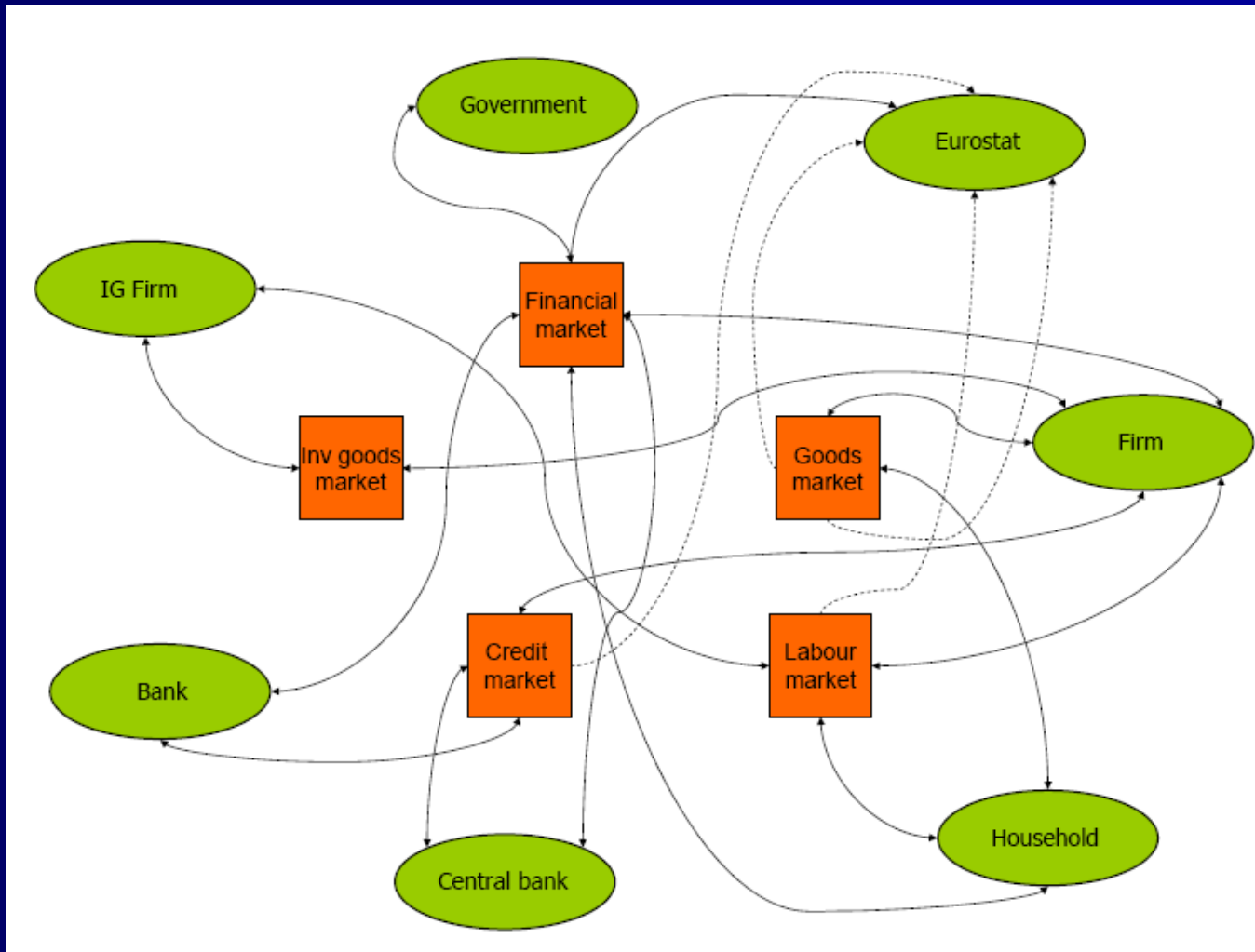
- Complex systems are characterised by the following features:
 - They are composed of interacting “agents”
 - These agents may have simple behavioural rules
 - The interaction among the agents means that aggregate phenomena are intrinsically different from individual behaviour
 - The network which governs the interaction is crucial
 - Agent based models can and should incorporate these features

A snapshot of EURACE



- EURACE represents a fully integrated macro-economy consisting of:
 - **the real sector** (production of consumption and capital goods with labor, capital goods and energy as factors of production and relative markets; technological innovation)
 - **the credit sector** (financing production plans of firms)
 - **the financial sector** (exchange of claims on the equity capital of producers as well as of governments liabilities)
 - **the public sector** (policy making, i.e., fiscal policy made by Governments and monetary policy set by the Central Bank)

Structure of the EURACE Macroeconomic Model

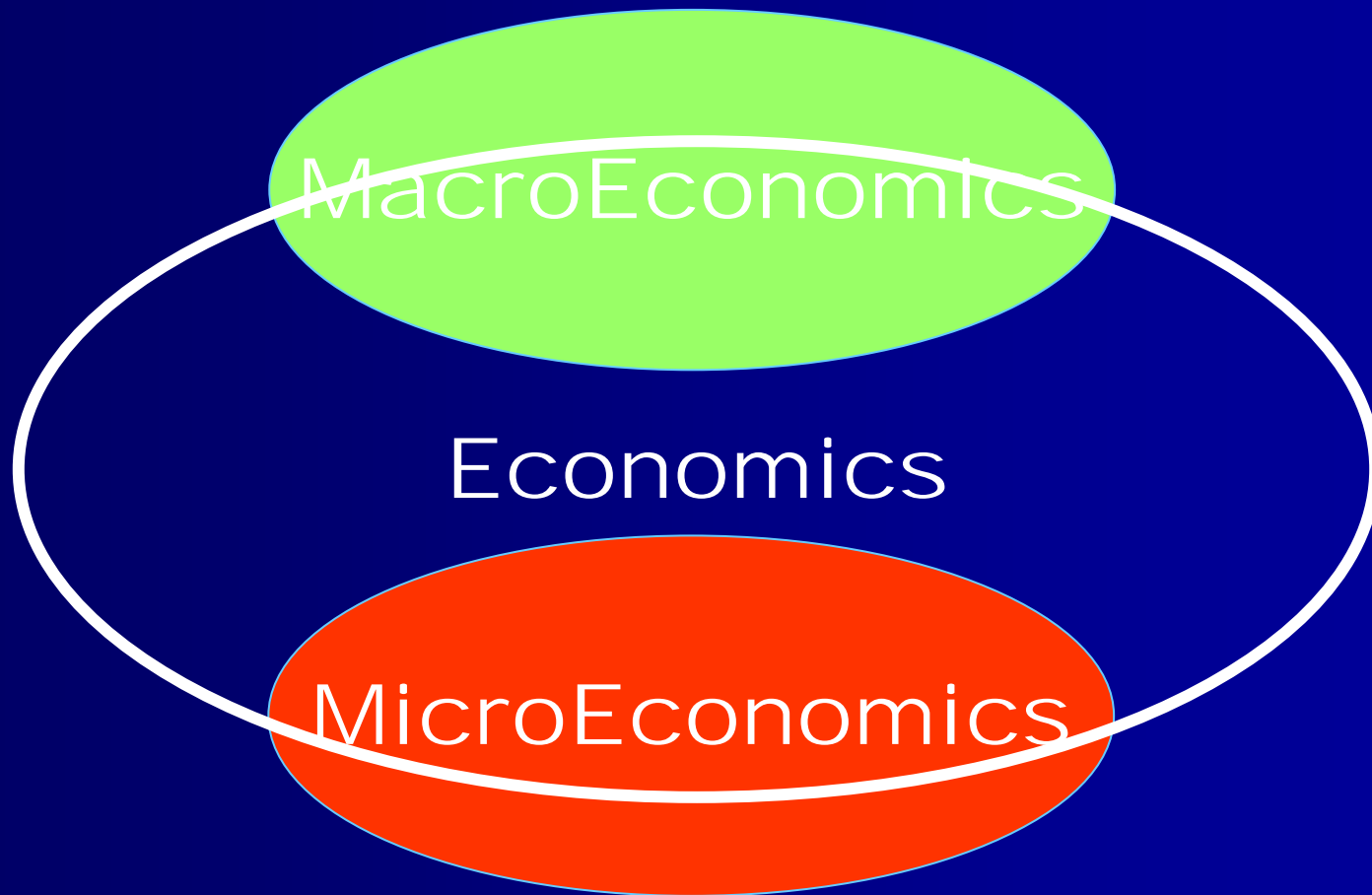


Why is *EURACE* different?



- Its main distinctive and innovative features are:
 - its closure
 - the presence of real and financial sides of the economy
 - the wide use of empirically grounded behavioural rules
 - the different levels of time and space granularity
 - asynchronous decision-making across different agents
 - the explicit spatial structure and local interactions
 - decentralized markets:
 - market clearing is not for granted
 - no law of single price
 - balance sheet approach in modeling agents
 - validation based on the reproducibility of well-known empirical regularities and the consistency of balance sheets
 - innovative software technology (FLAME, GUIs, parallelization)

The open economic question



Building Blocks: Agents



- Households
 - Buyer on Consumption Goods Market
 - Seller on Labor Market
 - Deposits at banks
 - Buyer/Seller of firm shares and government bonds

- Consumption Goods Producers
 - Buyer on Labor and Investment Goods Markets
 - Seller on Consumption Goods Markets
 - Loans from banks
 - Distributes dividends to shareholders

- Investment Goods Producer
 - Buyer on Labor Market
 - Seller on Investment Goods Market
 - Loans from banks
 - Distributes dividends to shareholders

Building Blocks: Agents



- Commercial Banks
 - Collect deposits from households
 - Give loans to firms
 - Access standing facilities of the central bank

- Government
 - Decides fiscal policies
 - Receives taxes
 - Pays unemployment benefits
 - Issues bonds

- Central bank
 - Sets monetary policies

Building Blocks: Markets



- Consumption Goods Markets
 - Consumption goods producers offer (and store) goods at selected geographically distributed local market outlets
 - Consumers visit their local outlets and make purchasing decisions based on price information they collect about the goods offered at the outlets
 - Suppliers on the consumption goods market act globally (without spatial frictions) whereas consumers buy locally

Building Blocks: Markets



- Labor Market
 - Firms post job vacancies based on planned output.
 - Searching workers send applications based on posted salaries.
 - Firms rank applications based on skills and make offers.
 - Workers rank offers (wage - commuting costs), compare best offer to their reservation wage and accept/reject.
 - **Labor Market is global with spatial frictions**

Building Blocks: Markets



■ Financial Market

- Households trade stocks and bonds
- Households strategy are based on prospect theory
- Firms issue or buyback stocks
- Governments issue T-bills when needed
- Assets prices are set by a clearing house
- **Financial Market is global**

Building Blocks: Decision Rules



- Strong micro-foundation of decision rules:
 - Firms and Households act rule-based using backward looking expectations.
 - Households decisions in the financial market are based on prospect theory
 - Operational decisions of firms are modelled using standard decision rules from the Operations Management literature:
 - Pricing (markup)
 - Inventory and Production Planning
 - Savings/consumption decisions of household are based on empirically-founded rules derived from the buffer-stock theory of consumption, see Deaton (1991) and Carrol (1993)
 - Purchasing Decisions of Households are modelled using standard logit-models from the Marketing literature

The balance sheet approach



- A double-entry balance sheet with a detailed account of all monetary and real assets as well as monetary liabilities is defined for each agent.
- Monetary and real flows given by agents' behaviors and interactions determine the period by period balance sheet dynamics.
- A stock-flow model is then created and used to check that all monetary and real flows are accounted for, and that all changes to stock variables are consistent with these flows.
- This provides us with a solid and economically well-founded methodology to test the consistency of the model and it increases the credibility that can be attached to the model's results

Household (H): balance sheet overview



Assets	Liabilities
M^h : liquidity deposited at a given <i>bank</i>	(none)
n_g^h : government bonds holdings	
n_f^h, n_b^h : equity shares holdings of firm f and bank b	

Financial wealth:

$$W = M^h + \sum_{f \in \{\text{firms}\}} n_f^h p_f + \sum_{b \in \{\text{banks}\}} n_b^h p_b + \sum_{g \in \{\text{governments}\}} n_g^h p_g$$

p_f, p_b : daily price of equity shares issued by firm f and bank b , respectively

p_g : daily price of the bond issued by government g

Firm (f): balance sheet overview



Assets	Liabilities
M^f : liquidity deposited at a given <i>bank</i>	D_b^f : debts to <i>banks</i>
I_m^f : inventories at <i>malls</i>	E^f : equity
K^f : physical capital	

M^f , I_m^f updated daily following firms' cash flows and sales

K^f , and D_b^f updated updated monthly (at the first day of the month to act)

Bank (b): balance sheet overview



Assets	Liabilities
M^b : liquidity deposited at the <i>central bank</i>	D^b : standing facility (debts to the <i>central bank</i>)
L_f^b : loans to firms	M_h^b : households' deposits at the bank
	M_f^b : firms' deposits at the bank
	E^b : equity

Government (g)



Assets	Liabilities
M^g : liquidity deposited at the central bank	D^g : standing facility with the central bank n^g : number of outstanding bonds

Government budget:

Revenues: taxes on corporate profits and household labor and capital income;

Expenses: unemployment benefits, transfer and subsidies.

Central Bank (c): balance sheet overview



Assets	Liabilities
n_g^c : Government bonds (QE)	outstanding fiat money
M^c : liquidity	M_g^c : Governments liquidity
L_b^c : loans to banks (standing facility)	M_b^c : banks reserves
	E^c : equity

With quantitative easing (QE), the central bank purchases government bonds using money it creates from nothing (fiat money), and so expands its balance sheets.

Verification rules



- Balance sheet accounting identities can be devised across agents and used to test the model and validate implementation
- Examples:

$$\sum_f \sum_b L_f^b = \sum_f \sum_b D_b^f$$

$$\sum_h M^h = \sum_b \sum_h M_h^b$$

...also at aggregate level



$$\left(\sum_h M^h + \sum_f M^f \right) + \left(\sum_b E^b \right) + \left(\sum_g M^g + M^{CB} \right)$$

private sector deposits + banks' equity + public sector deposits

=

$$\left(\text{constant} + \sum_g n_g^{CB} p_g^* \right) + \left(\sum_b \sum_f L_f^b \right)$$

fiat money + credit money



Do Capital Requirements Affect Long-Run Output Trends?

based on M. Raberto, A. Tegli, S. Cincotti (2011). Debt Deleveraging and Business Cycles. An Agent-Based Perspective. Economics Discussion Papers, No 2011-31. <http://www.economics-ejournal.org/economics/discussionpapers/2011-31>

Motivation 1/2



- The purpose of this work is to study the problem of debt and leverage by means of an agent-based model and simulator of the economy.
- We argue that the agent-based approach is better suited to deal with a realistic view of the economy, and is able to take into account the complex pattern of interactions in the credit markets, like networks topologies, credit rationing, bankruptcy waves and information cascade effects, which are important issues that can cause the unfolding of debt-induced recessions.

Motivation 2/2



- Furthermore, despite the attempts in the new Keynesian literature (Bernanke and Gertler (1990, 1995); Greenwald and Stiglitz (1993); Kiyotaki and Moore (1997); Eggertsson and Krugman (2010)) to incorporate debt and financial factors, the investment-finance linkage is still considered as a propagator mechanism of shocks which are exogenous with respect to the economy.
- Conversely, the agent-based approach is able to emphasize the role of the investment-finance link not just as a propagator of exogenous shocks but as a crucial source of financial instability and business cycles.

The role of debt



- It can then be argued that the boom-bust credit cycle of the 2000's has played a significant role in the developments of the great financial crisis (Keen, 2009) and that is still playing a central role in shaping the future prospects of developed economies.
- Despite the prominence of debt in discussion about current economic difficulties, perhaps surprisingly, it is quite common to abstract from debt in most mainstream economic modelling, as for the DSGE models (DeGrauwe, 2010) currently adopted by major central bank and policy makers.
- A recent pioneering attempt to include debt in a DSGE framework has been done by (Eggertsson, 2010).

Firms' financial needs



- Firms' financial needs (computed monthly) are:
 1. Interest payments due to current debt
 2. Debt installment payment
 3. Taxes
 4. Expected costs for planned production and investments
 5. Dividends

- Pecking order theory (Myers and Majluf, 1984) is followed:
 - Firms rely first on internal liquidity to meet payments;
 - If external financing is required, firms do prefer debt to equity and demand credit to banks;
 - If firms are rationed in the credit market, they issues new shares and sell them in the stock market.

- If external funding is not sufficient:
 - Firms reduce their financial needs first by cutting down dividends, then by scaling down production and investment plans
 - if payments can not be fulfilled, firms go the firm goes into insolvency (negative equity) or illiquidity (positive equity) bankruptcy.

The credit market



- Firm f send a loan request λ_f to a randomly chosen bank b .
- Insolvency probability π_f of the loan λ_f (i.e., its risk weight) is given by:

$$\pi_f = 1 - \exp\left(-\frac{D_f + \lambda_f}{E_f}\right)$$

(D_f : debt of firm f . E_f : equity of firm f)

- The bank then informs the firm about the amount of loan allowed $l_f \leq \lambda_f$ and the interest rate that would be applied.
- l_f is constrained by a Basel II like condition:

$$L_b + \pi_f \cdot l_f \leq \alpha \cdot E_b$$

(L_b : risk-weighted loan portfolio. E_b : equity of bank b)

- The interest rate is the CB rate plus a mark-up based on the risk and the loan amount.

The reference context



- The central bank simply updates, with monthly frequency, the base interest rate r^{cb} in order to fill the gap with inflation.

$$r^{cb} = \max \left(r^{cb} + \frac{\pi_m}{12}, r_{min}^{cb} \right)$$

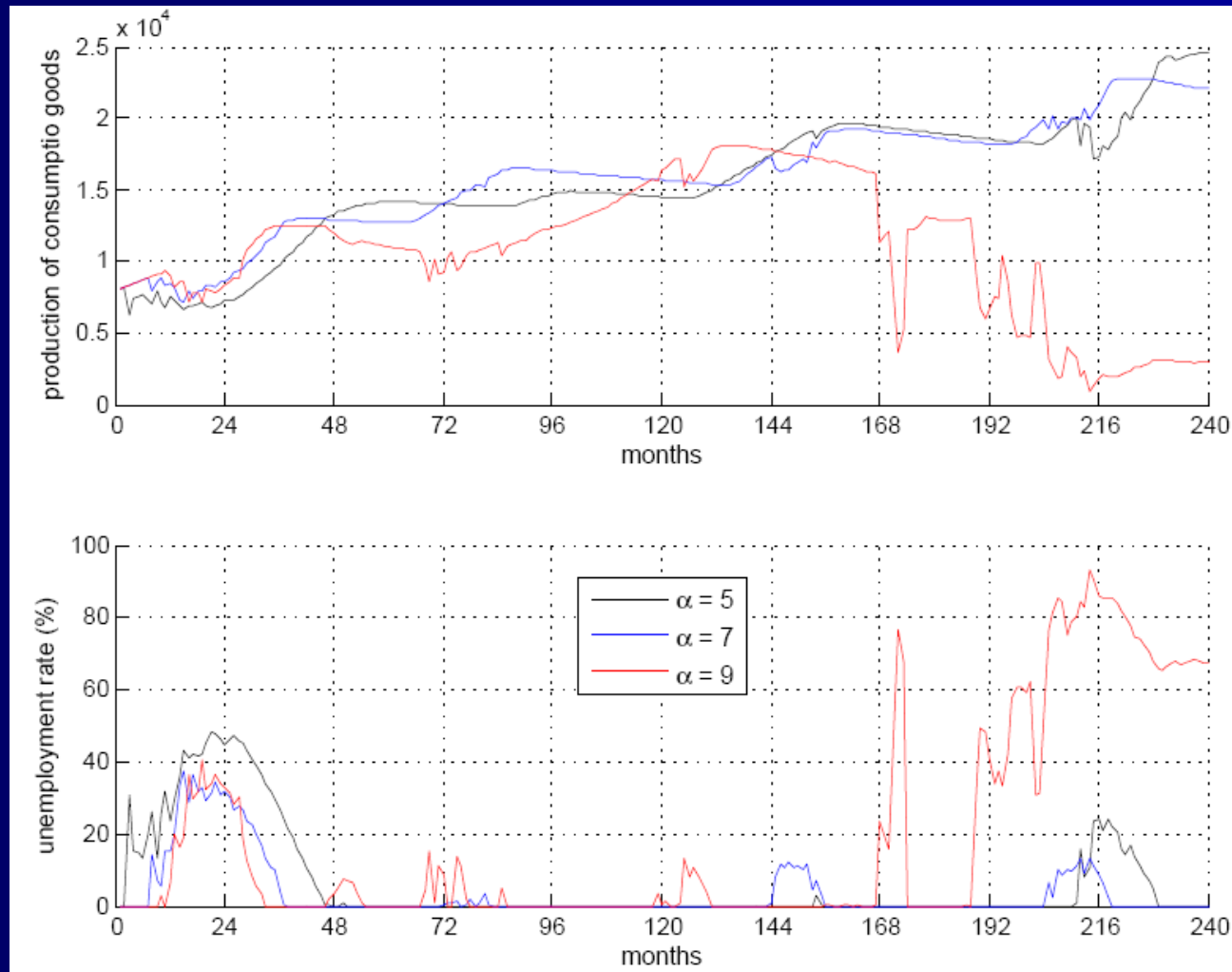
- This rule simply connects the policy rate with the inflation rate.
- Different values of the capital adequacy ratio α for the banks (Basel II)

Computational experiments

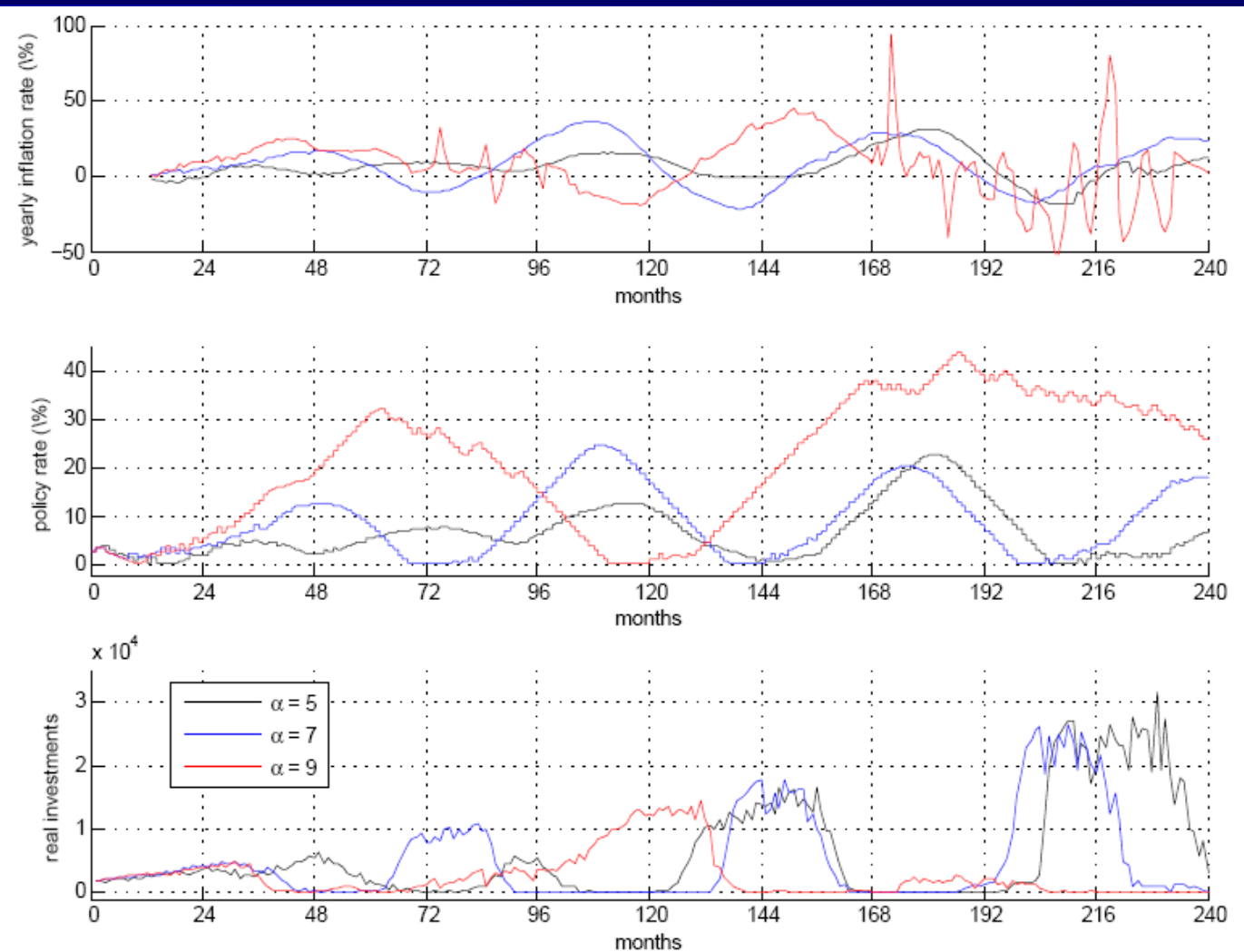


- 2,000 households, 20 firms, 3 banks
- 20 years of simulation
- Different levels of equity capital requirements for banks $\alpha = 5$, $\alpha = 7$, $\alpha = 9$.
- Qualitative approach
 - economic time-paths of the main variables of the artificial economy
- Robustness of results
 - average values of 15 computational experiments with different random seeds

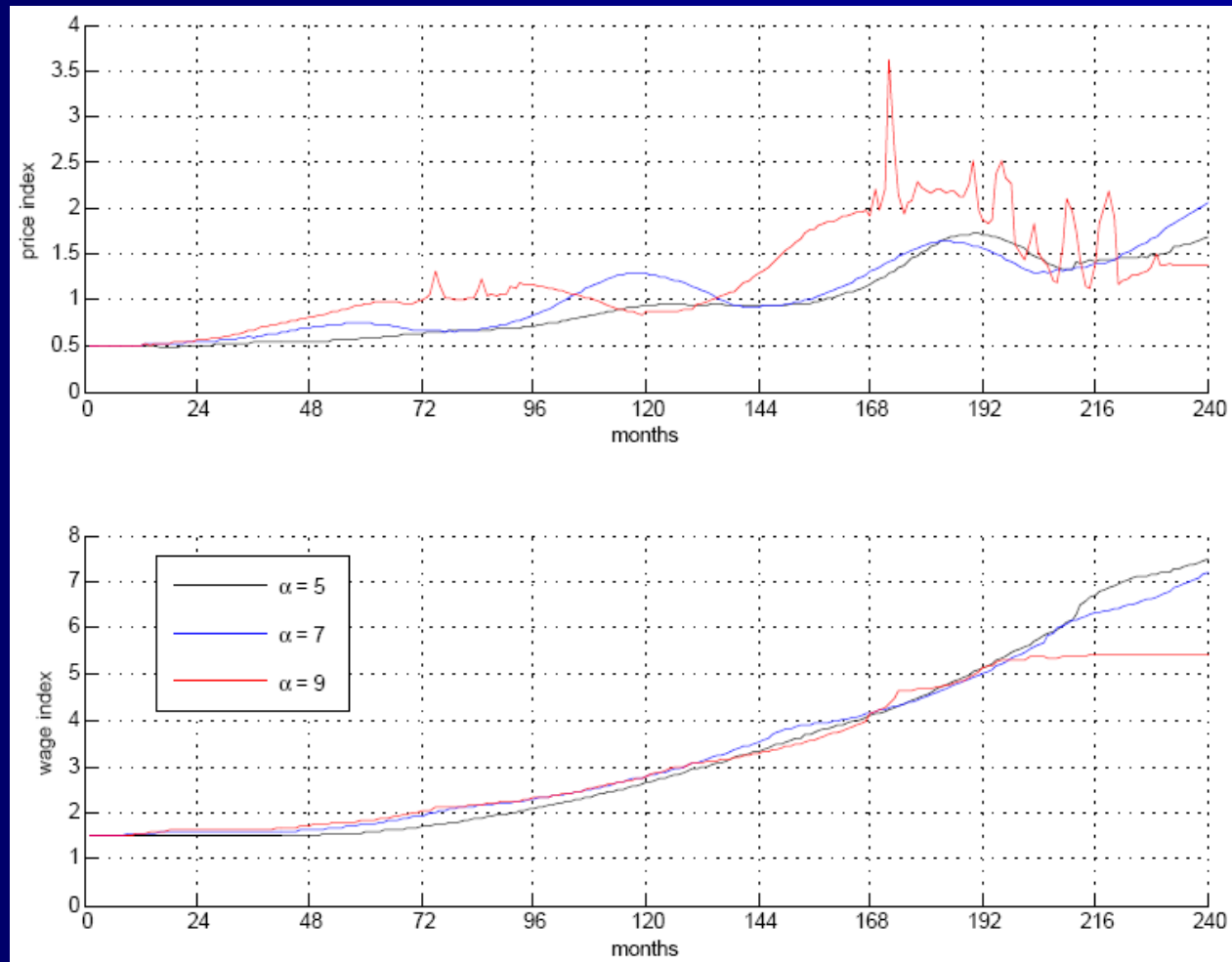
Simulation paths for production and unemployment



Simulation paths for inflation, central bank interest rate, and investments



Simulation paths for price and wage index



Remarks 1/2



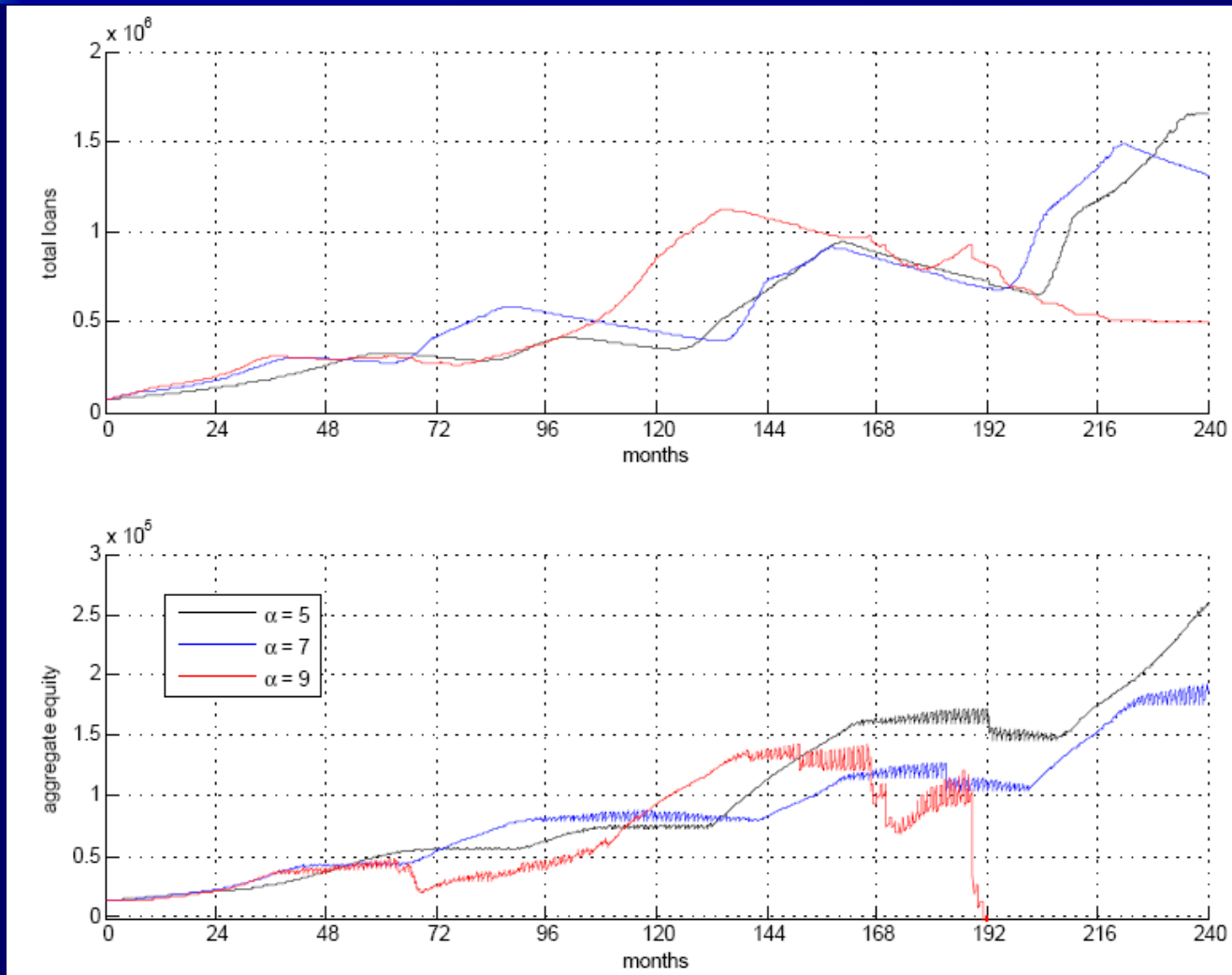
- Three stylized behaviors
 - a long term growth due to capital accumulation
 - alternative periods of growth and recession (business cycles)
 - sudden falls that are usually, but not always, followed by correspondent recoveries.

Remarks 2/2

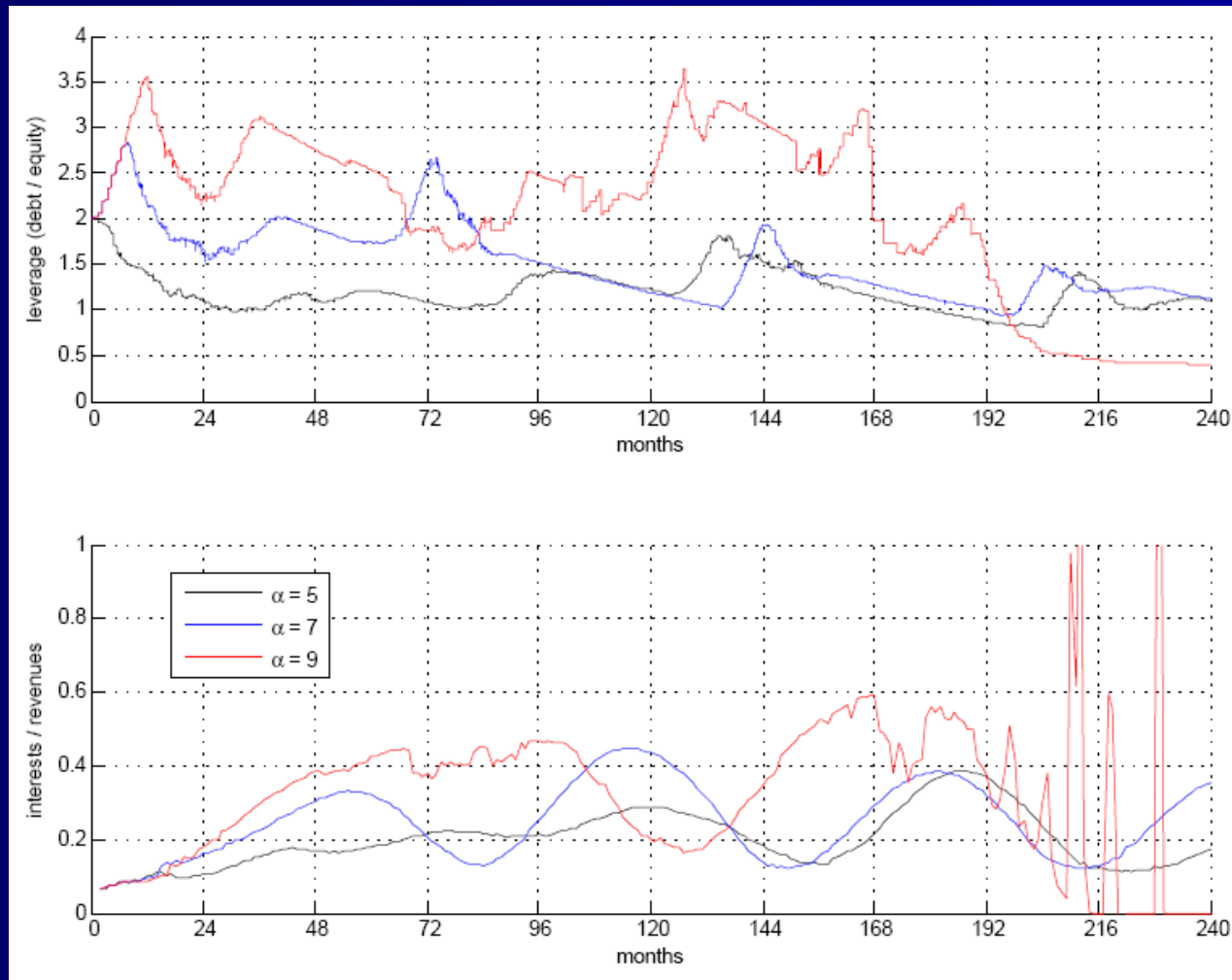


- The time-paths allows one to understand the nature of the business cycles
 - In a period of full employment there is a stronger pressure on wages, that tend to rise firms costs and therefore prices, that are set according to a mark-up rule
 - A higher inflation drives an increase of interest rates and investments costs, inducing a spiral that raises prices again
 - This mechanism goes on until the interest rate is sufficiently high to disincentive investments
 - the peak of the business cycle is followed by a period of lower investments that can lead to recession due to capital depreciation
 - that inflation peaks are characterized by a lag with respect to production peaks
 - Full employment usually persists for a while after the production peak, inducing a further growth of wages and prices until production declines after the peak as consequence of a contraction of investments
 - In the last part of the cycle, the decrease of inflation affects interest rates and firms start again to invest more, raising production and labor demand, thus affecting wages and prices, and closing the cycle

Simulation paths for total outstanding loans (credit) and banks aggregate equity



Simulation paths for firms' financial indicators (debt over equity and interest expenditures over revenues)

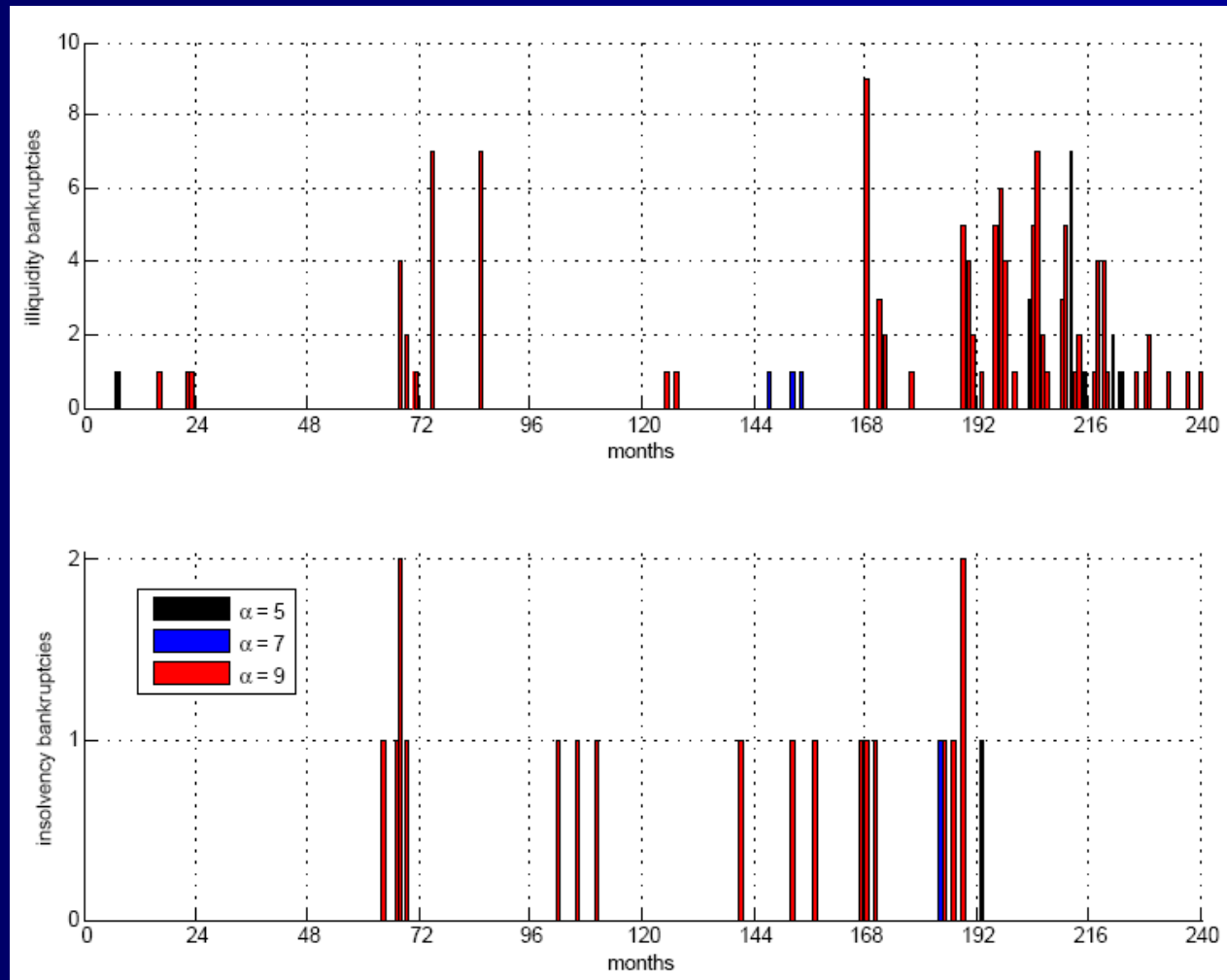


Remarks



- Total loans show a cyclical trend which is very similar to business cycles in production
 - firms finance their production plan mainly by asking loans to banks and therefore an increase of total credit is generally associated with economic growth
- When total credit and production are growing, interest over revenues is decreasing
 - the revenues are obviously growing
 - the higher debt burden affects firms in the next months, when they will have to pay interests for the borrowed loans.
- The more critical period for the productive sector is after a production peak, when a recession starts and interest expenses are still very high
 - interest over revenues is very high and firms are financially fragile
 - some firm with low revenues can go into bankruptcy and, if the economic system is also structurally fragile, the result can be a bankruptcies chain with disastrous consequences

Monthly number of insolvency and illiquidity bankruptcies



Remarks



- During the recession some firms go into insolvency bankruptcy
 - insolvency bankruptcy (where firms have negative equity) implies a partial write-off of debt that clearly affects banks equity
- This equity fall seriously cuts the lending capacity of the banking system
- Capital requirement is no more fulfilled, banks have to reduce new loans issuing, and firms are inevitably rationed in the credit market
- A chain of illiquidity bankruptcies is shown, affecting firms that still have a positive equity but that are unable to roll-over debt

Short vs long run



First 4 years

α	consumption goods production	unemployment rate (%)	total loans outstanding	firms' leverage
5.0	8386 (48)	30.84 (0.58)	146424 (500)	1.19 (0.01)
6.0	9154 (109)	23.24 (1.15)	173790 (1837)	1.55 (0.02)
7.0	9800 (65)	15.48 (0.58)	196693 (1091)	2.00 (0.03)
8.0	10096 (53)	10.88 (0.67)	208303 (1376)	2.41 (0.03)
9.0	10159 (64)	9.80 (0.78)	216077 (1298)	2.69 (0.03)

20 years

α	consum. goods production	invest. goods production	real GDP level	unemployment rate (%)
5.0	15165 (60)	4641 (149)	19807 (160)	7.88 (0.24)
6.0	15541 (46)	5106 (139)	20647 (172)	5.76 (0.34)
7.0	15547 (98)	5484 (115)	21031 (131)	4.59 (0.29)
8.0	13335 (801)	4211 (503)	17546 (1293)	12.50 (3.39)
9.0	12048 (467)	3377 (336)	15425 (789)	16.01 (1.93)

Nominal and financial variable in the long run



α	banks' equity	total loans	price index	wage index
5.0	67491 (2476)	459736 (10202)	0.83 (0.01)	2.82 (0.04)
6.0	77698 (5416)	543180 (21367)	0.92 (0.02)	3.07 (0.06)
7.0	90412 (3292)	652317 (17922)	1.05 (0.01)	3.33 (0.03)
8.0	27038 (23646)	599194 (43341)	1.16 (0.03)	3.23 (0.09)
9.0	14998 (20914)	620504 (35786)	1.19 (0.02)	3.14 (0.05)

α	interest rate (%)	firms' leverage	illiquidity bankruptcies	insolvency bankruptcies
5.0	6.67 (0.15)	1.94 (0.96)	17.7 (2.5)	0.5 (0.2)
6.0	7.83 (0.29)	1.47 (0.14)	12.7 (1.7)	1.3 (0.3)
7.0	9.97 (0.23)	2.14 (0.25)	17.3 (2.3)	2.7 (0.7)
8.0	16.06 (1.78)	2.56 (0.14)	71.0 (19.9)	8.3 (1.7)
9.0	18.24 (1.29)	5.28 (0.79)	99.1 (13.3)	13.1 (1.0)

Remarks 1/2



- Results show that the debt accumulation by the corporate sector is able to foster economic growth in the short run, but excessive leverage of the private sector may cause waves of bankruptcies, credit rationing and significant GDP drops in the long run.
- The relevance of the computational results reside in their resemblance with the recent developments of advanced economies, which have been characterized first a by period of easy credit and high growth, then by a nearly collapse of the financial system and a severe economic recession that ended in a slow recovery, characterized by a prolonged period of deleveraging.

Remarks 2/2



- Two major points can therefore be drawn from our results.
 - debt and private sector leverage play a crucial role in the business cycles dynamics and can not be neglected in a complete macroeconomic model
 - it can be argued that the AB models can be considered as a reliable scientific environment and an useful computational facility where to investigate some of the most important economic problems of present days

Confidence in our theoretical models



- The “central problem of depression-prevention has been solved,” , Robert Lucas 2003 presidential address to the American Economic Association.
- In 2004, Ben Bernanke, chairman of the Federal Reserve Board, celebrated the « Great Moderation » in economic performance over the previous two decades, which he attributed in part to improved economic policy making.

... but then the crisis



- Speaking of the “efficient markets hypothesis”

« The whole intellectual edifice collapsed in the summer of last year »

Alan Greenspan, testimony to House of Representatives Committee on Government Oversight and Reform, October 23rd 2008

The screenshot shows the official website of the United States House of Representatives. At the top, there is a navigation bar with links for Visitors, Educators and Students, Media, Doing Business with the House, and Employment. A search bar is located in the top right corner. Below the navigation bar is a header section with the House of Representatives logo and a 'FIND YOUR REPRESENTATIVE' search box. The main content area displays search results for 'Testimony of Alan Greenspan'. The results list several entries, including a hearing transcript from October 23, 2008, a transcript from June 13, 2005, a prepared witness testimony from June 10, 2003, and a letter from October 2, 2008. A 'Refine Your Search' sidebar is visible on the right, showing a search filter for 'Testimony of Alan Greenspan' and a 'SEARCH AGAIN' button.

.... opens requests for new contributions



The screenshot shows the ECB website interface. At the top left is the ECB logo and 'EUROSISTEM'. The top navigation bar includes links for Home, Site Directory, Glossary, Links, Contact, Disclaimer & Copyright, and Search. There are also icons for RSS, a printer, and font size adjustments. Below the navigation bar is a horizontal menu with categories: The European Central Bank, Press, Events, Publications, Statistics, The Euro, Monetary Policy, and Payments & Markets. The main content area displays a press release titled 'Reflections on the nature of monetary policy non-standard measures and finance theory' by Jean-Claude Trichet, President of the ECB, dated 18 November 2010. The release includes an introduction and the beginning of the speech text. On the left side, there is a sidebar with a 'Back to Press' link and a 'Speeches & Interviews' section with a 'By date' filter showing a list of years from 2010 down to 1997. On the right side, there is an 'Events' section with a link to the '6th ECB Central Banking Conference'.

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Speeches & Interviews

– By date

- 2010
- 2009
- 2008
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- 2002
- 2001
- 2000
- 1999
- 1998 (EM/ECB)
- 1997 (EM)

+ By speaker

Reflections on the nature of monetary policy non-standard measures and finance theory

Speech by Jean-Claude Trichet, President of the ECB, Opening address at the ECB Central Banking Conference Frankfurt, 18 November 2010

1. Introduction

It is a great pleasure to open the ECB's 2010 Central Banking Conference.

As you know, we consider this event, which has been held every other year since 2000, as our institution's flagship conference.

I am therefore particularly pleased to see that so many central bank governors from around the world have taken up our invitation, as well as representatives from European institutions and governments, leading academics, financial market participants and many other friends of the ECB. This year, we also have about 30 graduate students from all over Europe with us. A very warm welcome to all of you, on behalf of the Executive Board and Governing Council of the European Central Bank.

As ever, the goal of the conference is to bring together central bankers, policy-makers, academics, market participants and other observers to exchange views on topics of crucial relevance to central banks. I am sure that you will all agree that the theme of the conference – "Approaches to monetary policy revisited: lessons from the crisis" – is both relevant and timely.

I think we have an inspiring work ahead of us for these two days: it is packed with a combination of papers and panels, and I am very much looking forward to our discussions.

Events

→ 6th ECB Central Banking Conference

<http://www.ecb.int/press/key/date/2010/html/sp101118.en.html>

...but classical recipes are still out there



FINANCIAL TIMES

June 12, 2011 9:59 pm

How to avoid our own lost decade

By Lawrence Summers



Even with the 2008-2009 policy effort that successfully prevented financial collapse, the US is now halfway to a lost economic decade. In the past five years, our economy's growth rate averaged less than one per cent a year, similar to Japan when its bubble burst. At the same time, the fraction of the population working has fallen from 63.1 per cent to 58.4 per cent, reducing the number of those in jobs by

more than 10m. Reports suggest growth is slowing.

- ... "This is no time for fatalism or for traditional political agendas."
- "The central irony of financial crisis is that while it is caused by too much confidence, borrowing and lending, and spending, it is only resolved by increases in confidence, borrowing and lending, and spending."

...and one can understand why...



Key features of the models used in the analysis of Basel Committee on Banking Supervision (BIS) for studying the economic impact of capital and liquidity requirements

Model	Model type	Reference country/ area	Estimated/calibrated	Features bank capital	Features bank liquidity	Key lending spread ¹
(1) Gerali et al (2010)	DSGE	euro area	largely estimated	yes	no	$i_l - i_d$
(2) Roger and Vlcek (2010)	DSGE	euro area	calibrated	yes	yes	$i_l - i_d$
(3) Roeger ² (2010)	DSGE	euro area	calibrated	yes	yes	$i_l - i_d$
(4) Christiano et al (2010)	DSGE	euro area	estimated	yes	yes	$i_l - i_d$
(5) Antipa et al (2010)	DSGE	euro area	estimated	no	no	$i_l - i_d$
(6) Roger and Vlcek (2010)	DSGE	US	calibrated	yes	yes	$i_l - i_d$
(7) Van den Heuvel (2008)	DGE	US	calibrated	yes	no	$i_l - i_d$
(8) Curdia and Woodford (2009)	DSGE	US	estimated	no	no	$i_l - i_d$
(9) Dellas et al (2010)	DSGE	US	calibrated	no	yes	$i_l - i_d$
(10) Meh and Moran (2008)	DSGE	US	calibrated	yes	no	$i_l - i_d$
(11) Locarno (2004)	Semi-structural	Italy	estimated	no	no	$i_l - i_d$ $i_b - i_d$
(12) Bank of England	Semi-structural	UK	estimated	no	no	<i>n.a.</i>
(13) Gambacorta (2010)	VECM	US	estimated	yes	yes	$i_l - i_m$

¹ i_l : interest rate on loans to firms; i_b : interest rate on long-term bonds; i_d : interest rate on bank deposits; i_e : return on bank equity; i_m : monetary policy rate. ² Model calibrated based on eight euro area countries.

Final Note



- EURACE project (EU IST FP6 STREP grant: 035086) has been developed within the part of the IST-FET proactive initiative "Simulating Emergent Properties in Complex Systems" IST-2005-2.3.4 (xi)
- Special thanks to M. Raberto and A. Teglio

For further information
silvano.cincotti@unige.it