Credit-driven bubbles and crises in the macroeconomic and financial system: the Eurace agent-based modelling approach

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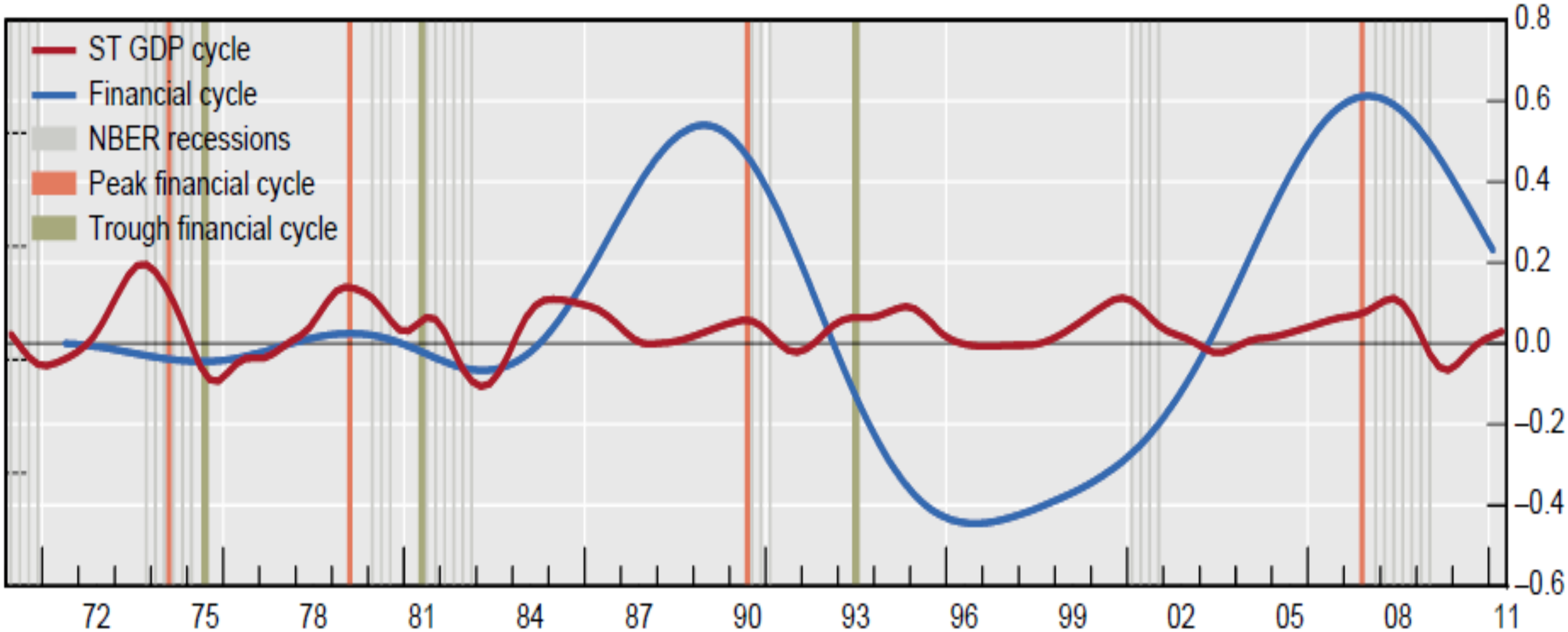
Outline

- Motivation for the ABM approach:
  - the role of debt
  - the crisis of economics
- The original Eurace model (2006-2009) and key results
- Eurace@Symphony (2013-2016):
  - model enrichment: the housing market (a new source of bubbles/crashes)
- Computational experiments and results
- Conclusions and Outlook

The role of debt

- It can be argued that the 2000s boom-bust credit cycle has played a significant role triggering the great recession (Keen, 2009) and that is still playing a central role in shaping the future prospects of developed economies.
- Despite this, perhaps surprisingly, it was quite common to abstract from debt in most mainstream economic modelling before the crisis (DeGrauwe, 2010)
- One of the first pioneering attempt to include debt in a DSGE framework has been done by Eggertsson & Krugman, 2010.

The financial and business cycles in the United States



Note: Pink and green bars indicate peaks and troughs of the combined cycle using the turning-point (TP) method. The frequency-based cycle (blue line) is the average of the medium-term cycle in credit, the credit to GDP ratio and house prices (frequency-based filters). The short-term GDP cycle (red line) is the cycle identified by the short-term frequency filter.

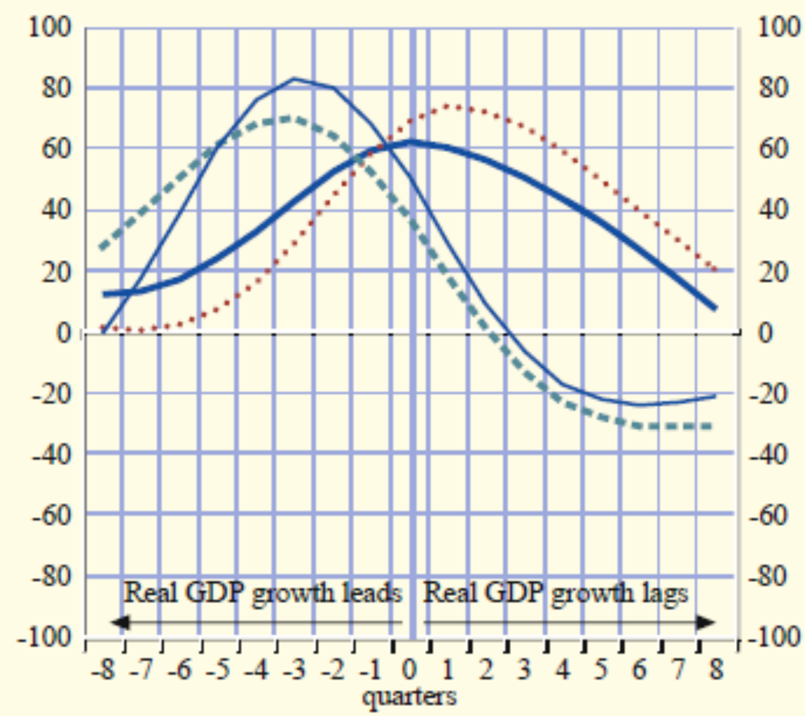
Source: Drehmann et al (2012) Bank for International Settlements

Eurozone data:

Chart D Correlation between real growth in household loans, real growth in non-financial corporation loans, sub-components of the two series, and real GDP growth for different leads/lags

(correlation between annual percentage changes; percentages)

- real loans to households
- real loans for house purchase
- real loans to non-financial corporations
- real short-term loans to non-financial corporations



Sources: ECB, Eurostat and ECB calculations.
Notes: Data are for the period between the first quarter of 1990 and the second quarter of 2013. Real series have been derived by deflating nominal series with the GDP deflator.

ECB Monthly Bulletin, October 2013, p. 21

From economic crisis to crisis of economics ?

- Paul Krugman feared that most macroeconomics of the past 30 years was "spectacularly useless at best, and positively harmful at worst" (The Economist, July 16th 2009).
- "Economics needs a scientific revolution" by J.-P. Bouchaud (Nature, October 30th, 2008)

The ABM approach: key features

- Agents' realistic adaptive behavior and expectations, limited rational capabilities and information.
- Emergent aggregate regularities from the behavior and interaction of many heterogeneous economic agents (e.g. endogenous defaults and crisis).
- Out-of-equilibrium dynamic behavior of the economy.
- Endogeneity of money and stock-flow consistent modeling (agents' balance sheets entries as the state variables of the system).

Overview of original EURACE model (EU FP6 project 2006-2009)

- The EURACE model represents a fully integrated agent-based model of the macro-economy consisting of:
  - **the real sector** (production of consumption and capital goods with labor, capital goods 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).

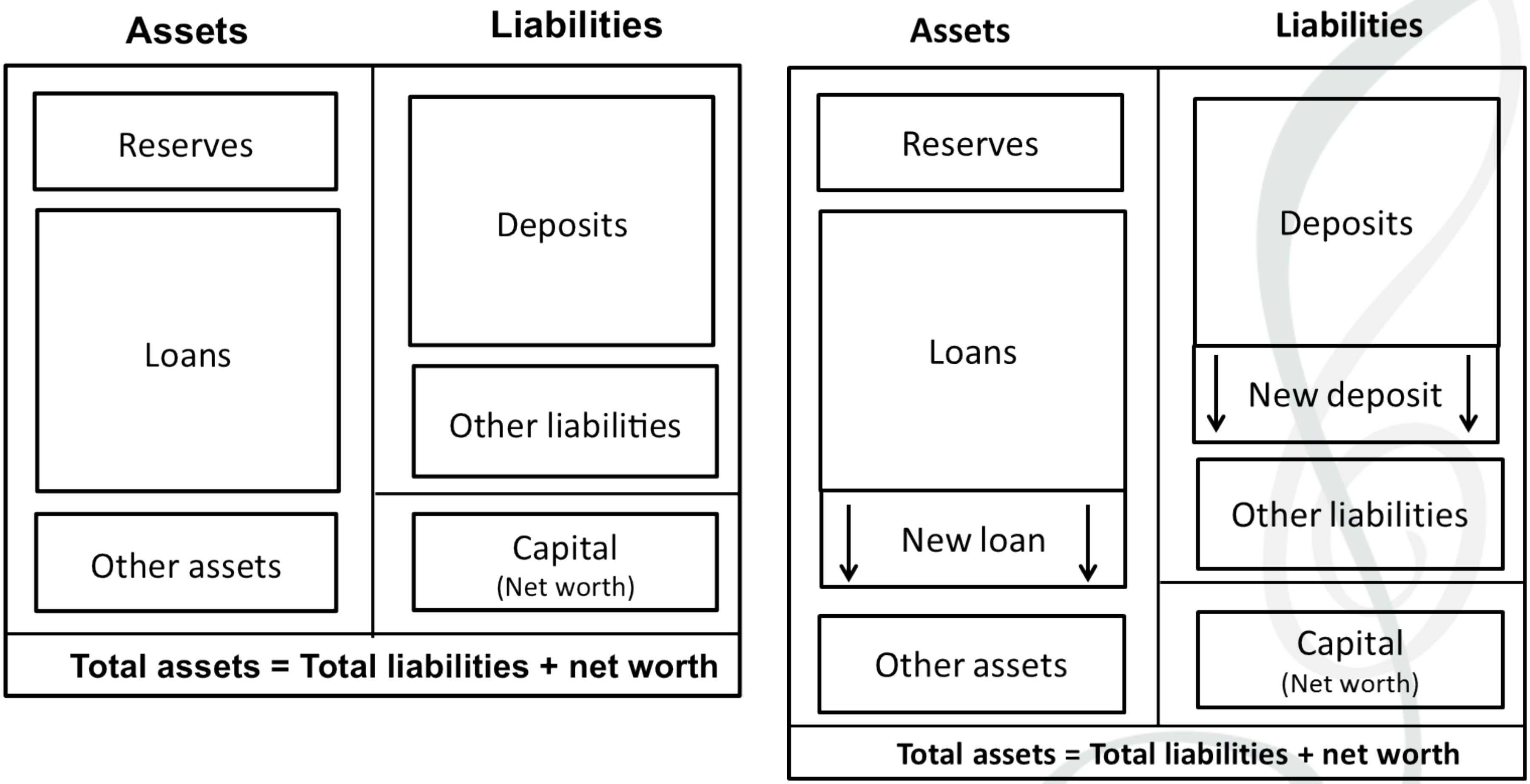
Key features of EURACE

- Technology: FLAME (www.flame.ac.uk), GUIs, parallelization.
- Realistic time scales and asynchronous interactions
- Decentralized markets (no Walrasian auctioneer except for the financial market):
  - market clearing is not for granted
  - no law of one price
- Adaptive and empirically grounded behavioral rules (optimization banned)
- Balance sheet approach in modeling agents
- Stock-flow consistency as the basic validation tool
- Endogenous money creation by banks' credit

Balance sheet of EURACE agents

AGENT	ASSETS	LIABILITIES
Household	Liquidity Equity Shares Gov. Bonds value	Equity
Consumption Good Producers	Liquidity Capital goods Inventories	Debt Equity
Capital Goods Producers	Liquidity	Equity
Bank	Liquidity Loans Gov bonds value	Deposits Standing facility with the central bank Equity
Government	Liquidity	Bonds Equity
Central Bank	Liquidity Loans to bank Gov Bonds Value	Outstanding fiat money Bank Liquidity Goverment Liquidity Equity

The process of credit money cration



McLeavy et al (2014), Money creation in a modern economy, BoE Quarterly Bullettin, 2014-Q1

Overview of Eurace 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 modeled 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

Credit market for corporate loans

- Bank *b* with equity and risk weighted loan portfolio W^b
- Firm *f* with debt D^f and equity E^f sends a loan request amount λ^f to bank b
- ω^λ is the risk weight of loan λ^f
- bank *b* is allowed to the firm *f* provided that its equity (capital) base E^b is at least a fraction κ of $W^b + \omega^\lambda \lambda^f$, i.e.

$$E^b \geq \kappa (W^b + \omega^\lambda \lambda^f)$$

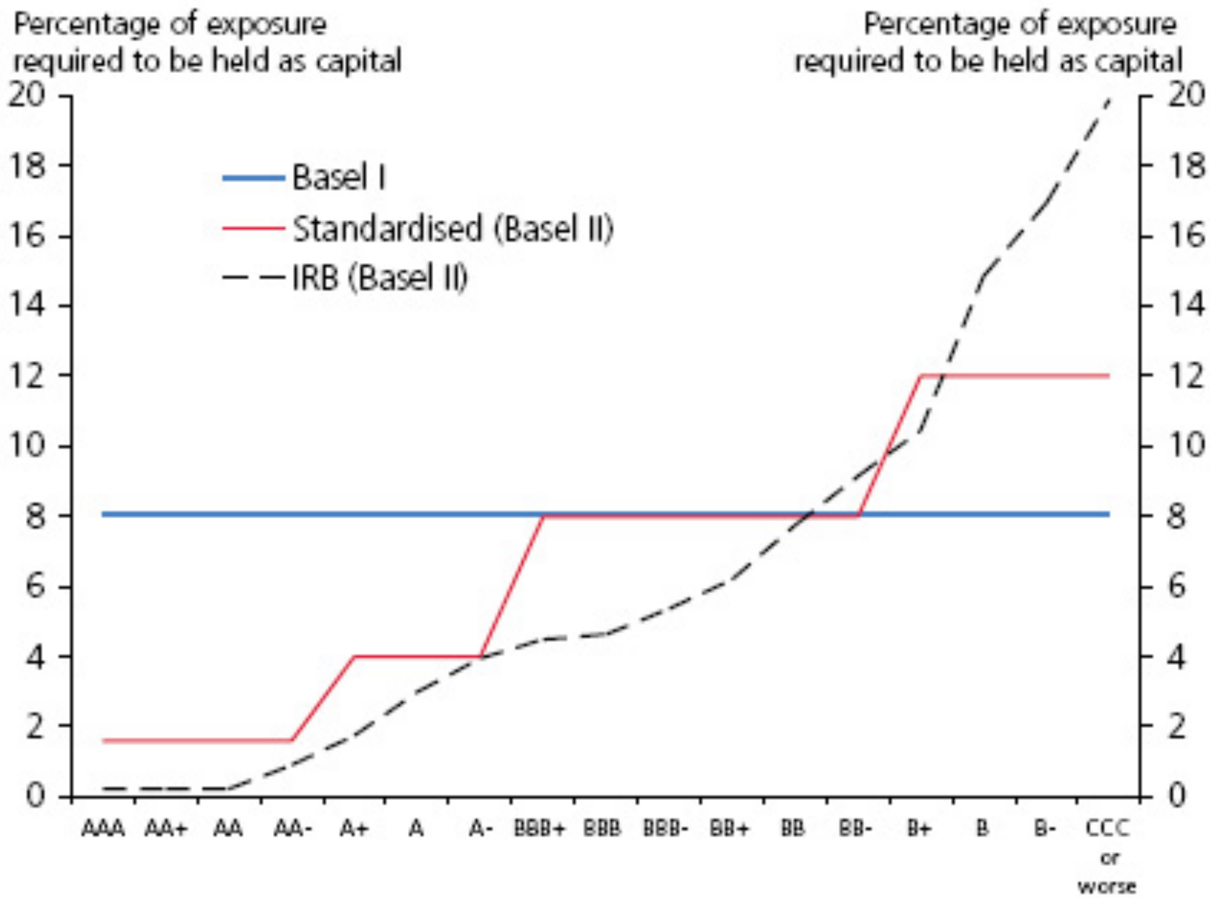
  (Basel II/III provisions for capital requirements)

- κ sets the minimum fraction of $W^b + \omega^\lambda \lambda^f$ needed as equity capital by bank *b* to cushion possible loan write-offs

Capital requirements in Basel frameworks

- Basel I (1988): κ fixed, no risk weighting of loans;
- Basel II (2004): κ fixed; risk weighting of loans depending on borrowers' credit rating;
- Basel III (2010): κ variable depending on macroeconomic conditions, risk weighting as well.

Capital requirement for corporate loan under Basel I and II



Yeh A., Twaddle J., Frith M. (2005). Basel II: A new capital framework. Reserve Bank of New Zealand: Bulletin, Vol. 68, No. 3

Loan risk weighting in Eurace

- Inspired by the Moody's KMV model, credit rating is measured by the distance to default (or default probability π^f) measured by its balance sheet entries:

$$\pi^f = \frac{D^f + \lambda^f}{D^f + \lambda^f + E^f}$$

- The risk weight ω^λ of the loan depends on the borrower's default probability π^f :

$$\omega^{\lambda^f} = 2.5(\pi^f)^3$$

- This cubic function has to be considered as an *ad-hoc* approximation of the Basel II internal ratings approach (IRB), after considering its graphical representation given in the previous figure.

Basel III: macroprudential capital requirements

- The Basel III global regulatory standard has been proposed in order to improve the resilience of the banking system
- This new framework presents a set of macro-prudential regulations with the objective to limit systemic risk
- Procyclical amplification of financial shocks through the banking system have been identified as a critical issue and, in order to cope with such procyclical dynamics, new countercyclical capital buffers regulations has been proposed
- The rational is to encourage banks to accumulate capital during good times and use it when the economic conditions are bad

Dynamic (macro-prudential) capital requirements in Eurace

- The rationale is that the capital requirement should be tighter when we are in "good times" (low unemployment rate or high aggregate credit growth) whereas should be relaxed when we are in "bad times" (high unemployment rate or low aggregate credit growth or even deleveraging)

- Unemployment rate as conditioning variable:

$$\kappa_t^u = \begin{cases} \kappa_{\max} - (\kappa_{\max} - \kappa_{\min}) \frac{u_t}{\bar{u}} & \text{if } u_t < \bar{u} \\ \kappa_{\min} & \text{if } u_t \geq \bar{u} \,. \end{cases}$$

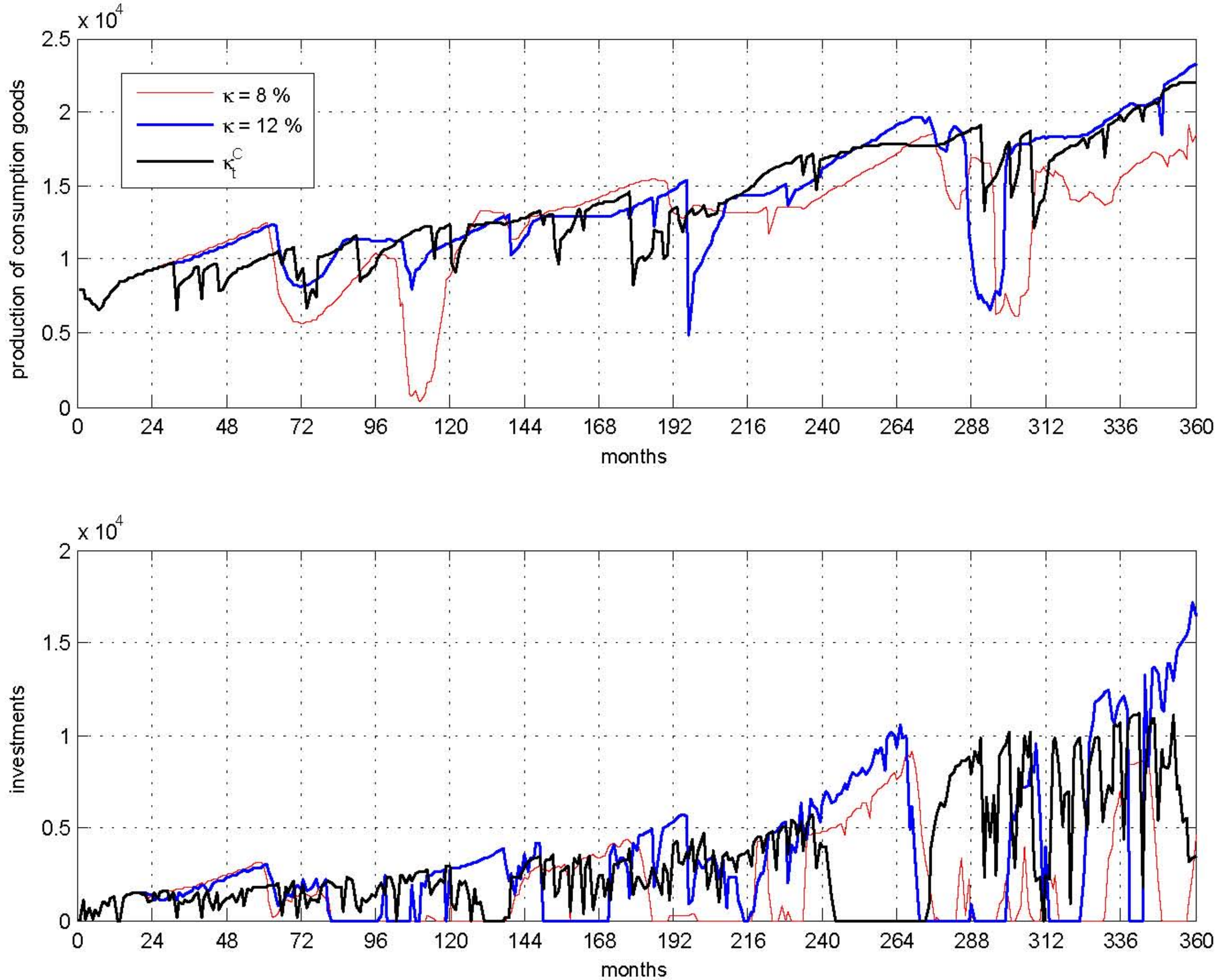
- Aggregate credit growth as conditioning variable:

$$\kappa_t^c = \begin{cases} \kappa_{\min} + (\kappa_{\max} - \kappa_{\min}) \frac{\Delta L_t}{\eta \, L_t} & \text{if } \frac{\Delta L_t}{L_t} < \eta \\ \kappa_{\max} & \text{if } \frac{\Delta L_t}{L_t} \geq \eta \,. \end{cases}$$

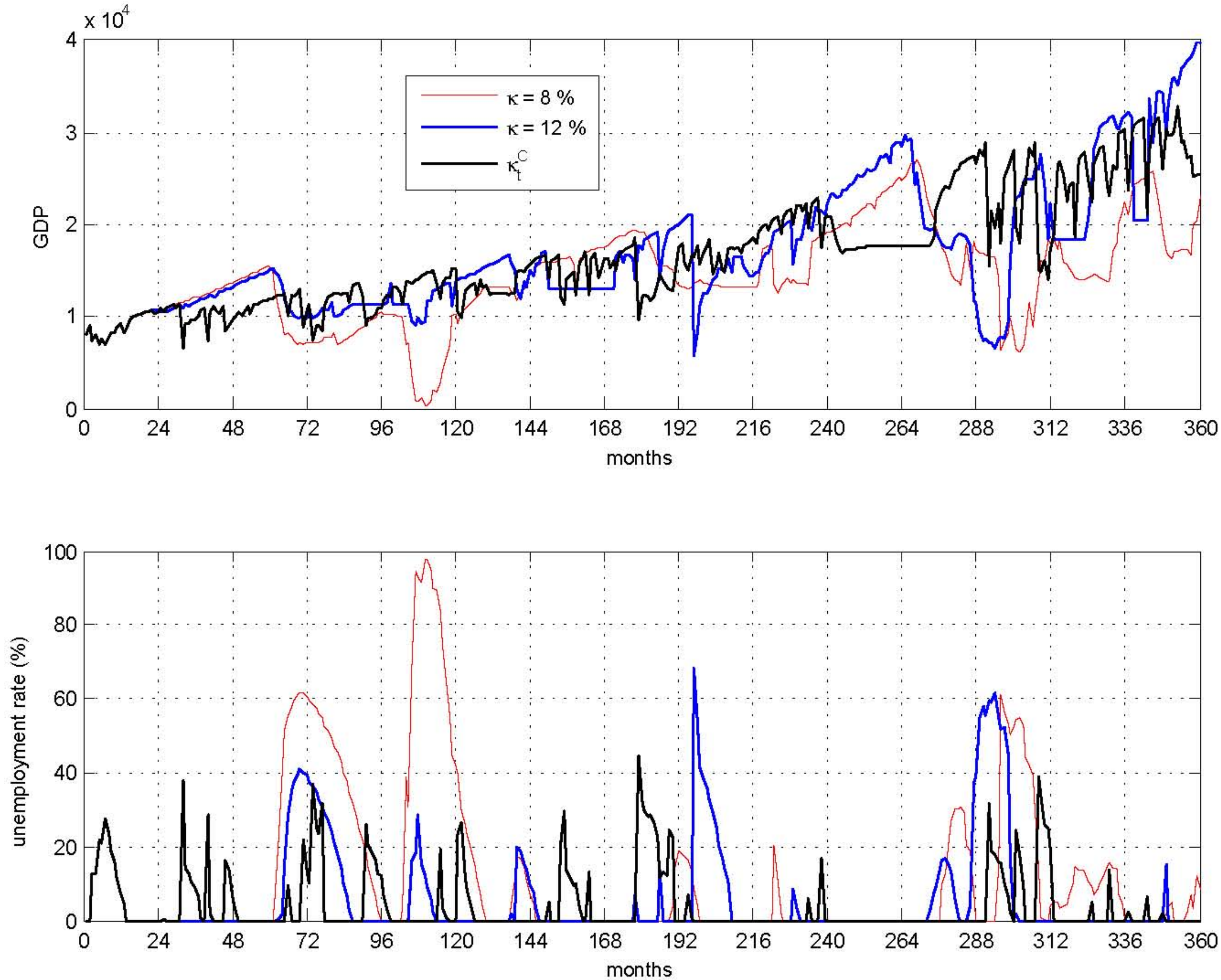
Computational experiments

- 2,000 households, 20 CGPs, 3 banks, 1 KGP, 1 Gov, 1 CB
- micro-prudential regulation:
  - fixed κ with κ = 8%; 10%; 12%
- macro-prudential regulation:
  - variable κ^u_t and κ^u_t with κ_{min} = 8% and κ_{max} = 12%
- U = 25% (threshold unemployment rate)
- η = 5% (threshold monthly credit growth rate)
- Time path of main economic indicators related to single simulations as well as the ensemble averages evaluated for different random seeds are shown

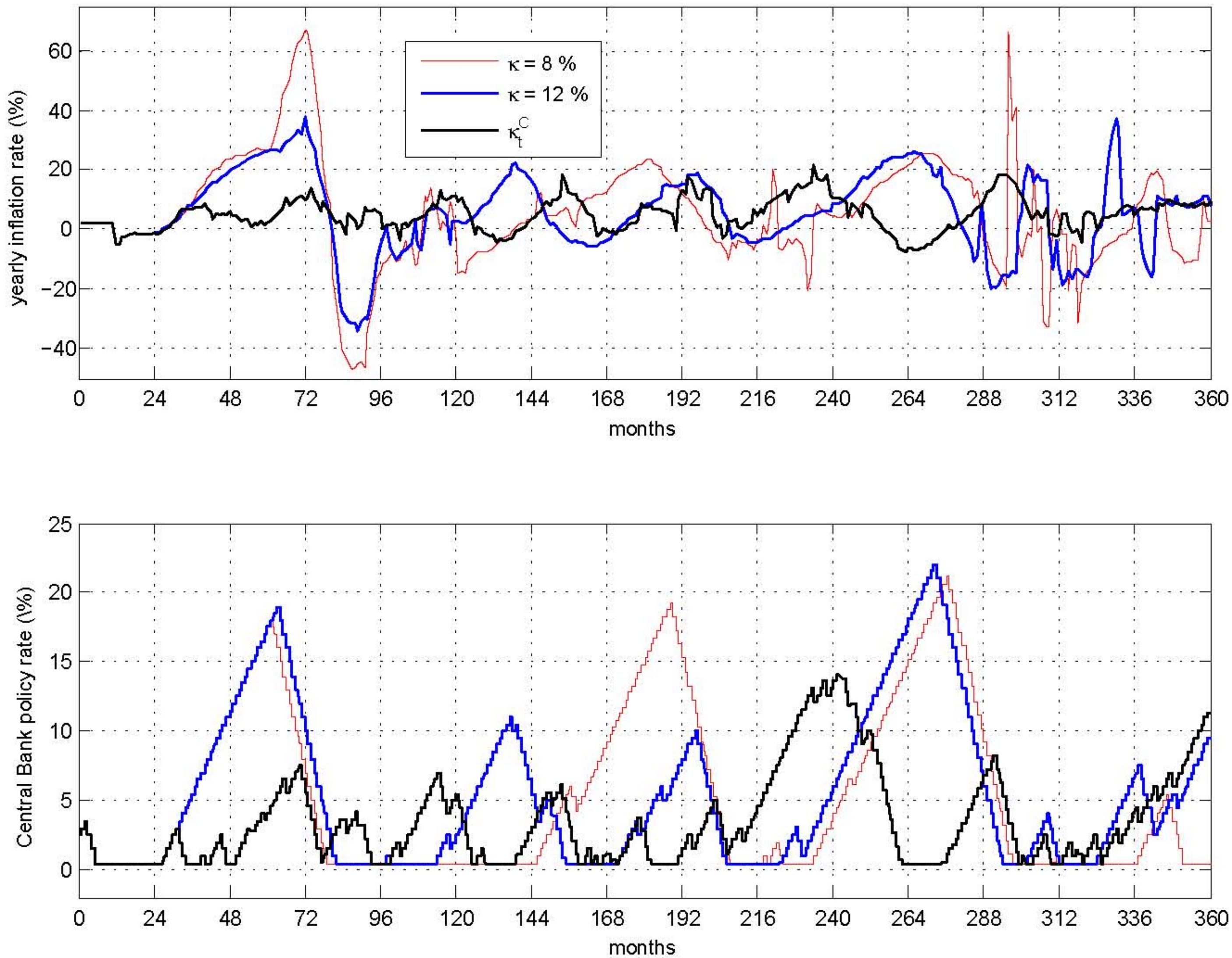
GDP components



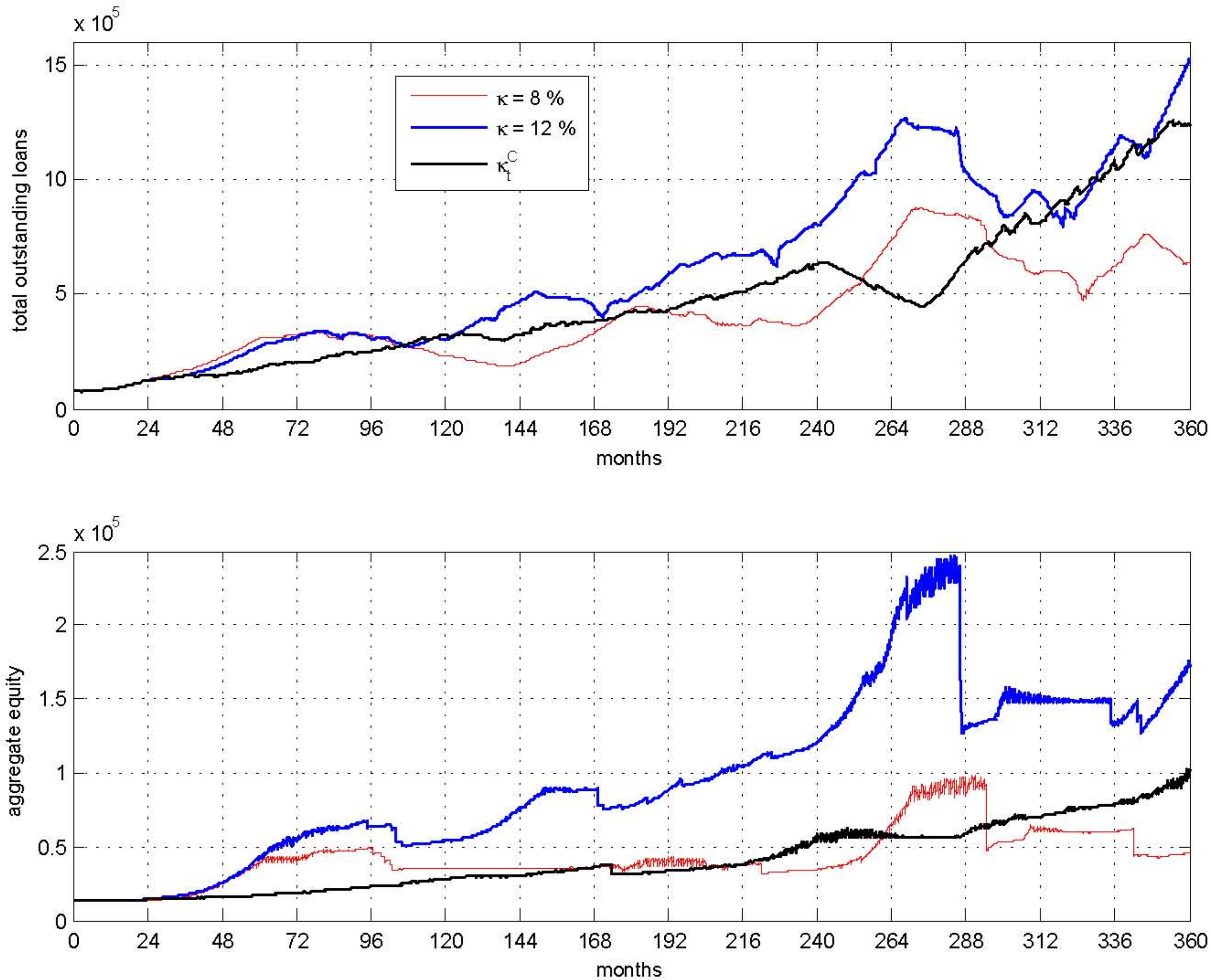
GDP and unemployment rate



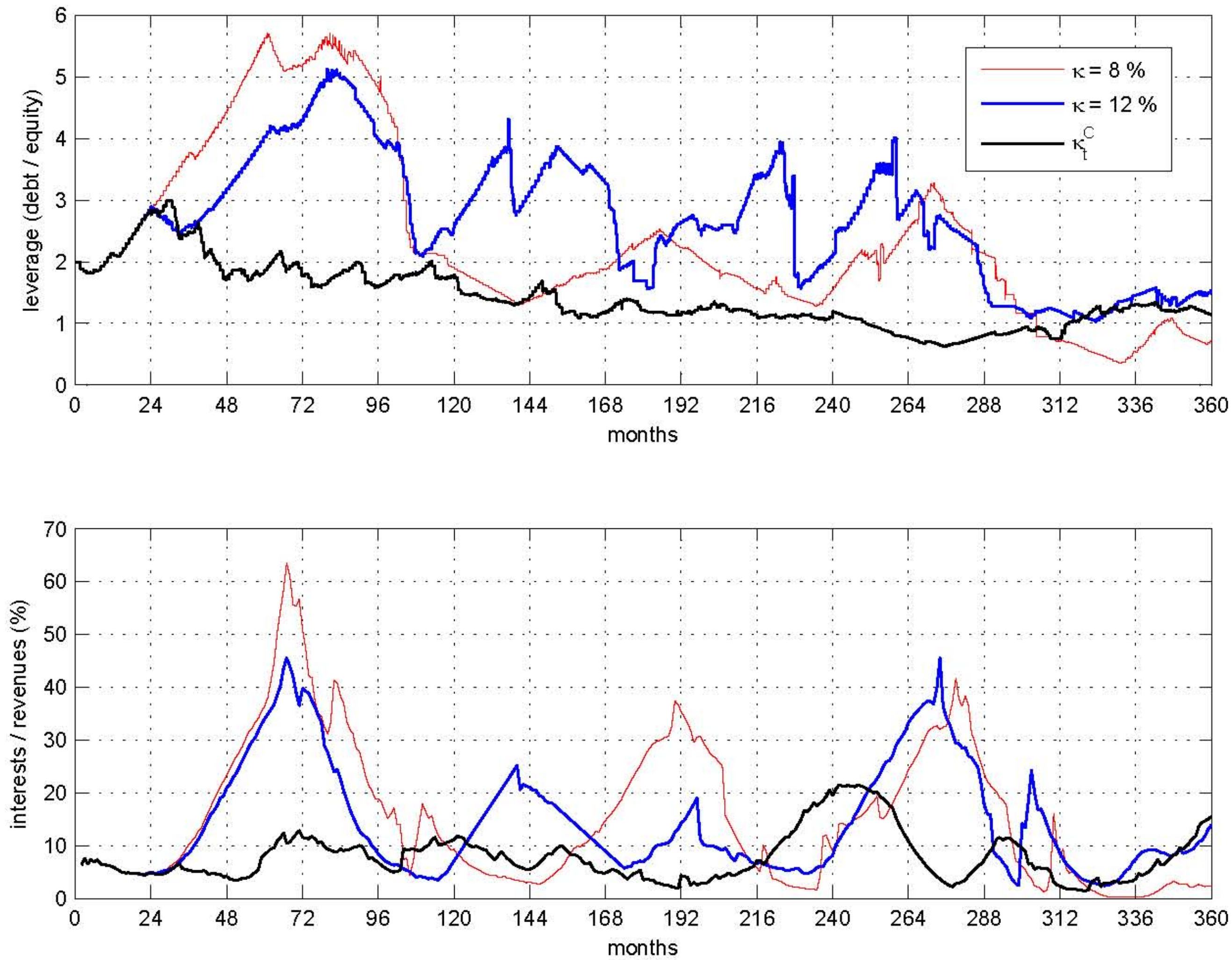
Yearly inflation rate and CB rate



Aggregate credit and aggregate banks' equity capital



Financial fragility indicators of firms



Comparison between the short run and the long run

κ (%)	cons. goods production	inv. goods production	unempl. rate (%)	banks' loans	firms' leverage
8	9629 (25)	1620 (14)	2.84 (0.18)	151393 (1042)	3.21 (0.02)
10	9530 (29)	1530 (18)	2.86 (0.18)	143659 (1090)	2.85 (0.02)
12	9486 (27)	1486 (14)	2.88 (0.18)	138126 (840)	2.60 (0.01)
κ_t^u	9411 (40)	1442 (24)	2.95 (0.20)	136749 (1246)	2.58 (0.02)
κ_t^c	8518 (57)	1069 (12)	7.54 (0.57)	121650 (512)	2.23 (0.01)

Values averaged over 20 different random seeds in the first 5 years of simulation. κ^u_t average value = 11.54, κ^c_t average value = 9.65.

κ (%)	cons. goods production	inv. goods production	unempl. rate (%)	banks' loans	firms' leverage
8	14296 (160)	3650 (188)	8.1 (0.5)	720375 (25922)	7.19 (0.85)
10	14637 (126)	3460 (154)	7.6 (0.4)	681196 (23748)	6.74 (0.58)
12	15081 (154)	3729 (137)	6.2 (0.4)	722717 (25495)	7.12 (1.26)
κ_t^u	15040 (157)	3686 (131)	5.5 (0.5)	698161 (17714)	6.76 (1.55)
κ_t^c	15419 (151)	3901 (103)	3.2 (0.4)	590332 (10978)	5.69 (3.31)

Values averaged over 20 different random seeds in the last 25 years of simulation. κ^u_t average value = 11.34, κ^c_t average value = 9.61.

Further statistics for the long run

κ (%)	price index	inflation rate (%)	wage index	interest rate (%)
8	1.53 (0.03)	5.92 (0.20)	6.76 (0.13)	8.41 (0.21)
10	1.53 (0.02)	6.12 (0.23)	6.84 (0.09)	8.61 (0.23)
12	1.55 (0.02)	6.33 (0.17)	7.03 (0.12)	8.82 (0.15)
κ_t^u	1.51 (0.02)	6.22 (0.21)	6.97 (0.12)	8.58 (0.14)
κ_t^c	1.43 (0.02)	6.13 (0.12)	7.27 (0.15)	6.90 (0.25)

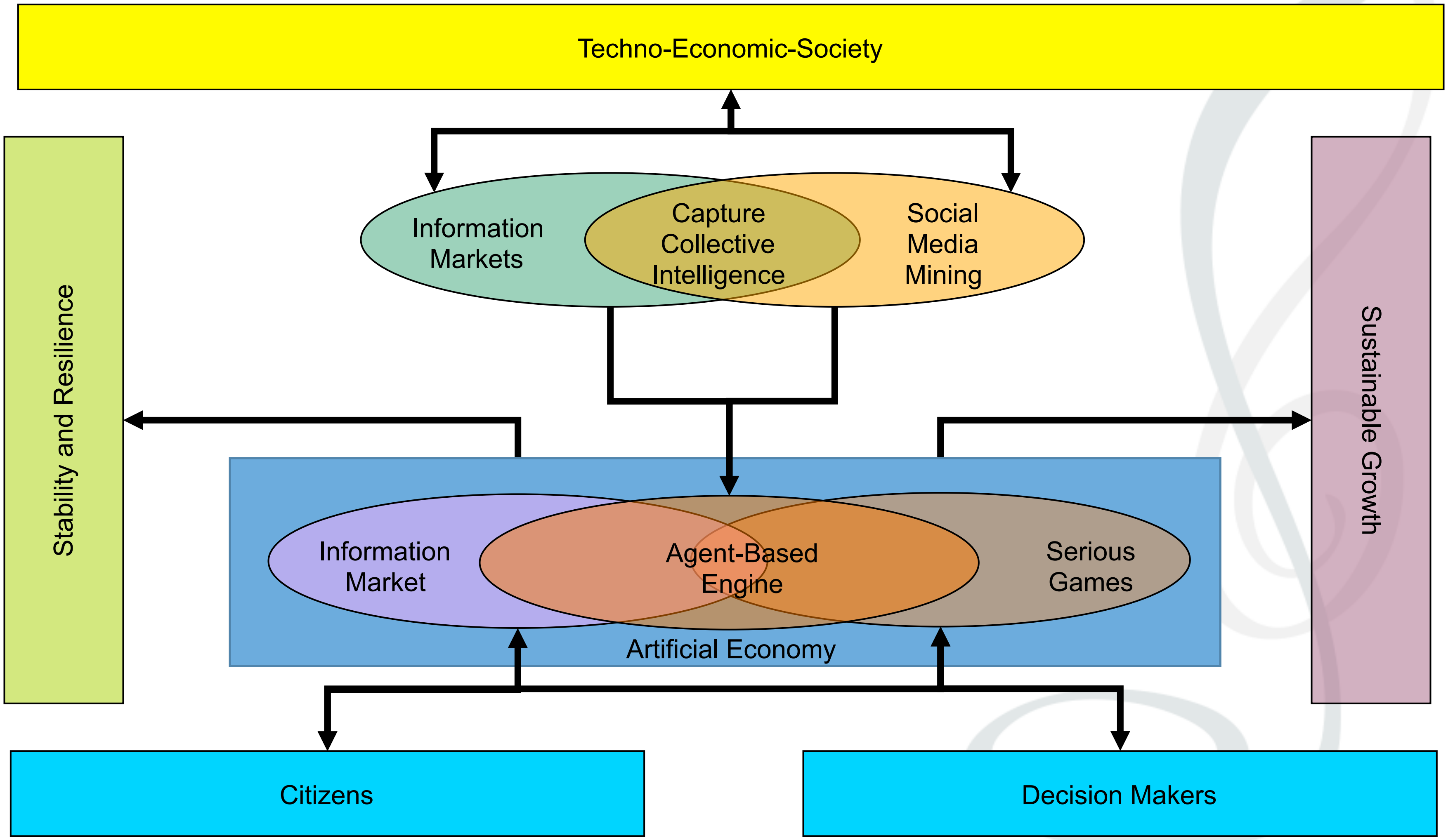
κ (%)	total loans	banks' equity	firms' leverage	illiquidity bankrupt.	insolvency bankrupt.
8	720375 (25922)	78003 (4331)	7.19 (0.85)	11.0 (0.5)	4.5 (0.2)
10	681196 (23748)	93022 (4280)	6.74 (0.58)	8.3 (0.4)	4.2 (0.1)
12	722717 (25495)	117812 (5448)	7.12 (1.26)	7.4 (0.4)	4.1 (0.2)
κ_t^u	698161 (17714)	105051 (3474)	6.76 (1.55)	9.0 (0.4)	3.8 (0.1)
κ_t^c	590332 (10978)	53261 (1841)	5.69 (3.31)	15.1 (0.8)	0.6 (0.1)

Values averaged over 20 different random seeds in the last 25 years of simulation.

Results: credit regulation and business cycles

- Results show that loose capital requirements (high bank leverage) boosts the economy in the short run but can affect the economic performance in the medium-long run, raising the financial fragility (or systemic risk) in the economic system and potentially triggering chains of firms insolvency bankruptcies.
- The situation is generally better when setting tighter capital requirements.
- Furthermore, results have shown that the dynamic (macro-prudential) regulation of capital requirements successfully stabilizes the economy and improves the main economic indicators.
- In particular, when the "credit rule" is adopted, the economic scenario seems to change in a significant way, showing a much more solid banking sector with a resulting positive effect on the real economy.

Eurace@Symphony (EF FP7 project 2013-2016)



The balance sheet of Eurace agents with HM

Agent	Assets	Liabilities
Household	Liquidity Housing units (NEW) Equity shares Gov bonds	Mortgages (NEW) Equity
Consumption goods producer (CGP)	Liquidity Inventories Capital Stock	Loans Equity
Capital goods producer (KGP)	Liquidity	Equity
Bank	Liquidity Loans Mortgages (NEW)	Deposits (Hous., CGP, KGP) Standing facility with CB Equity
Government	Liquidity	Gov bonds Equity
Central Bank (CB)	Liquidity Standing facility with Banks Gov bonds	Deposits (banks and gov) Fiat base money Equity

Eurace transaction flow matrix

	Households		CGPs		KGP	Banks		Government		Central Bank		
	Current	Capital	Current	Capital		Current	Capital	Current	Capital	Current	Capital	Σ
Consumption	$-$		$+$									0
Wages	$+$		$-$		$-$			$-$				0
Transfers	$+$							$-$				0
Investment				$-$	$+$							0
Taxes	$-$		$-$		$-$	$-$		$+$				0
Dividends	$+$		$-$		$-$	$-$						0
Coupons	$+$							$-$		$+$		0
Seigniorage								$+$		$-$		0
Mortgages' interests	$-$					$+$						0
Loans' to firms interests			$-$			$+$						0
Loans' to banks interests						$-$				$+$		0
CB interests payback						$+$				$-$		0
Current surplus(+)/ Deficit(-)	$-\Sigma_h \Delta E_h$	$+\Sigma_h \Delta E_h$	$-\Sigma_f \Delta E_f$	$+\Sigma_f \Delta E_f$	$-\Delta E_k$	$-\Sigma_b \Delta E_b$	$+\Sigma_b \Delta E_b$	$-\Delta E_G$	$+\Delta E_G$	$-\Delta E_{CB}$	$+\Delta E_{CB}$	0
Δ Debt(+)/ Credit(-)		$+\Delta$ Mortgages		$+\Delta$ Loans			$-\Delta$ Mortgages $-\Delta$ Loans $+\Delta$ Loans$_{CB}$				$-\Delta$ Loans$_{CB}$	0
Δ equity shares		$-\Sigma_f p_{E_f} \Delta n_{E_f}$		$+\Sigma_f p_{E_f} \Delta n_{E_f}$								0
Δ Gov.debt		$-p_G \Delta n_G$							$+p_G \Delta n_G$			0
Quantitative easing		$+p_G \Delta n_G$									$-p_G \Delta n_G$	0
Δ private liquidity/ banks deposits		$-\Sigma_h \Delta M_h$		$-\Sigma_f \Delta M_f$	$-\Delta M_k$		$+\Delta \mathrm{Dep}_b$					0
Δ Bank - Gov. liquidity/ central banks deposits							$-\Sigma_b \Delta M_b$		$-\Delta M_g$		$+\Delta \mathrm{Dep}_{CB}$	0
Δ Central bank liquidity											ΔM_{CB}	0
Σ	0	0	0	0	0	0	0	0	0	0	0	

Key indentities among monetary aggregates

$$\boxed{\Sigma_h \Delta M_h + \Sigma_f \Delta M_f + \Delta M_k + \Sigma_b \Delta E_b + \Delta M_G + \Delta E_{CB} = \Delta\text{Mortgages} + \Delta\text{Loans} + \text{QE}}$$

$\Sigma_h \Delta M_h + \Sigma_f \Delta M_f + \Delta M_k + \Sigma_b \Delta E_b + \Delta M_G = \Delta$Mortgages + ΔLoans + QE - Loans to banks interests + CB Interests Payback + Seignoirage - Coupons

$\Sigma_b \Delta M_b + \Delta M_G = \Delta\text{Loans}_{CB}$ + QE - Loans to banks interests + CB Interests Payback + Seignoirage - Coupons

$\Sigma_b \Delta M_b + \Delta M_G + \Delta E_{CB} = \Delta\text{Loans}_{CB} + \text{QE}$

HM overview

- We focus on modeling the financial (mortgage lending) and structural (decentralized exchange) aspects, not on the behavioral issues.
- Households are the only traders in the market.
- Housing units are homogenous.
- Households are selected randomly to enter the market with an exogenous probability, <u>except for a special case: fire sales by over-indebted households</u>.
- Selected households can be buyers or sellers with equal probability.
- Sellers post selling prices based on the latest market price.
- Buyers in the market are price takers, they are randomly queued and each buyer gets his turn while there is supply of housing.

HM supply side (I)

- **Random selling orders:**

  given the latest average monthly market price, P_H the price posted by the *i-th* seller (randomly selected to enter the market) is:

$$p_H^i = P_H(1 + \varepsilon^i) \qquad \mathrm{i} \in \{\text{selected sellers}\}$$

where ε^i is a random draw by seller *i* from a uniform distribution defined in the interval between 0 and a positive constant.

HM supply side (II)

- **Fire sales orders:**

  Households, whose periodic mortgage payments (interests and principal) are higher than a given income ratio ϕ^{fs}, are willing to sell housing (fire sale) at a discounted value to get rid of mortgage:

$$p_H^j = P_H(1-\hat{\varepsilon}^j) \quad j \in \{\text{hous. in financial distress}\}$$

  where $\hat{\varepsilon}^j$ is a random draw by household j from a uniform distribution defined in the interval between 0 and a positive constant.

HM demand side

- Buyers are price takers and are randomly queued in the market.
- Each buyer at his turn selects the cheapest available housing unit to buy.
- The buyer always a mortgage to a bank to cover the entire cost of the mortgage.
- We allow for adjustable-rate mortgages with periodic payments characterized by both interests and part of the principal

Mortgage lending

- The bank grans the mortgage provided the total mortgage payments of the applicant are lower than a given debt service-to-income (DSTI) ratio of his income, i.e.

$$\sum_m R^m + R^{m^*} \leq \mathrm{DSTI}\,(Z_l + Z_e)$$

- $\Sigma_m R^m + R^{m^*}$ is the sum of quarterly payments (principal and interests) related to both present mortgages $\Sigma_m R^m$ and the new mortgage m^*.
- $Z_l + Z_e$ is the sum of quarterly labor and capital income

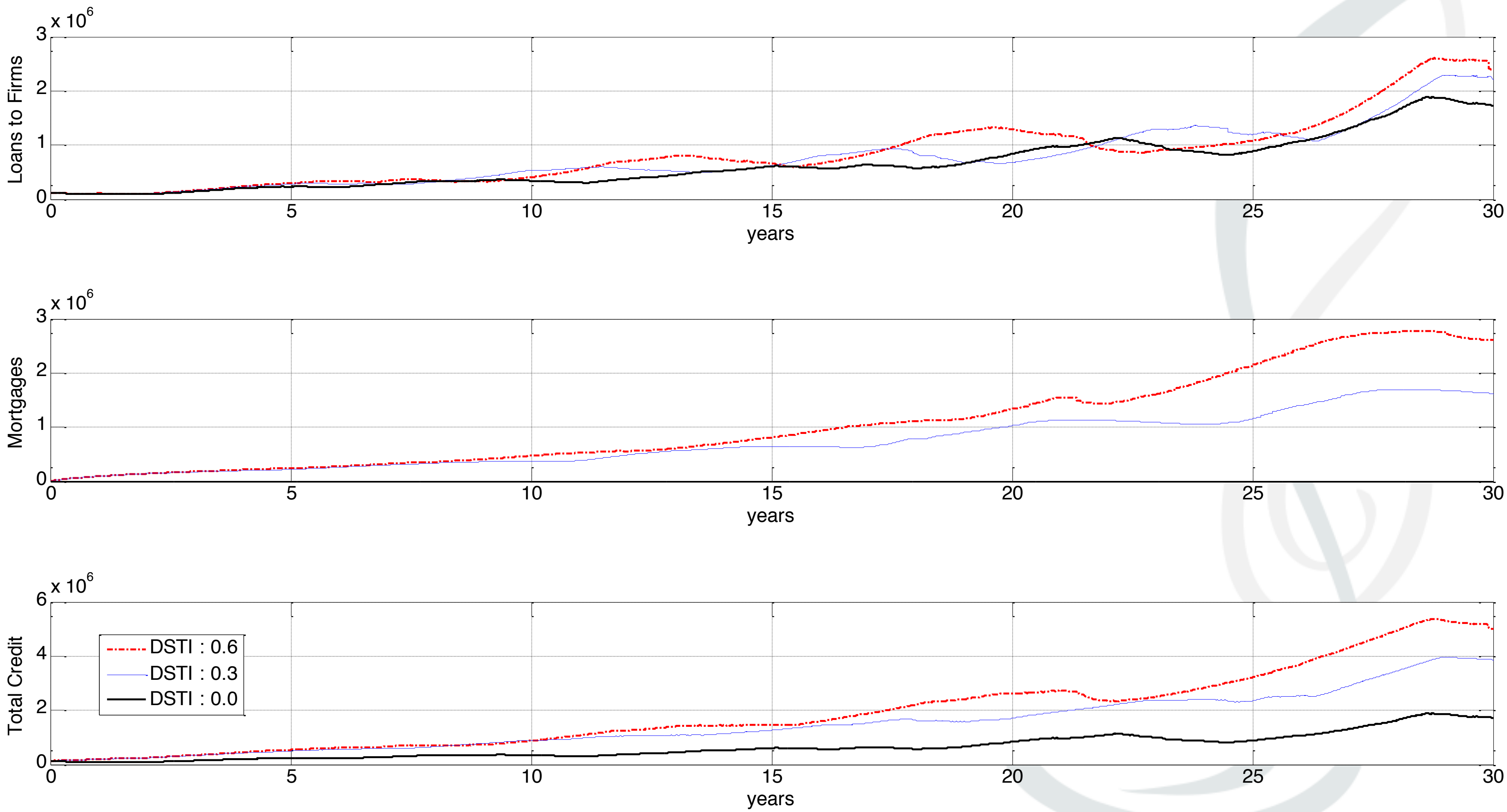
Mortgages defaults

- Given the adjustable rate mortgages, households are subject to interest rate risk and may default in their mortgage if mortgage payments become higher than a given ratio ϕ^{d} of their income.
- We set: DSTI < $\phi^{fs} < \phi^{d} < 1$
- Households defaults cause banks equity write-off.

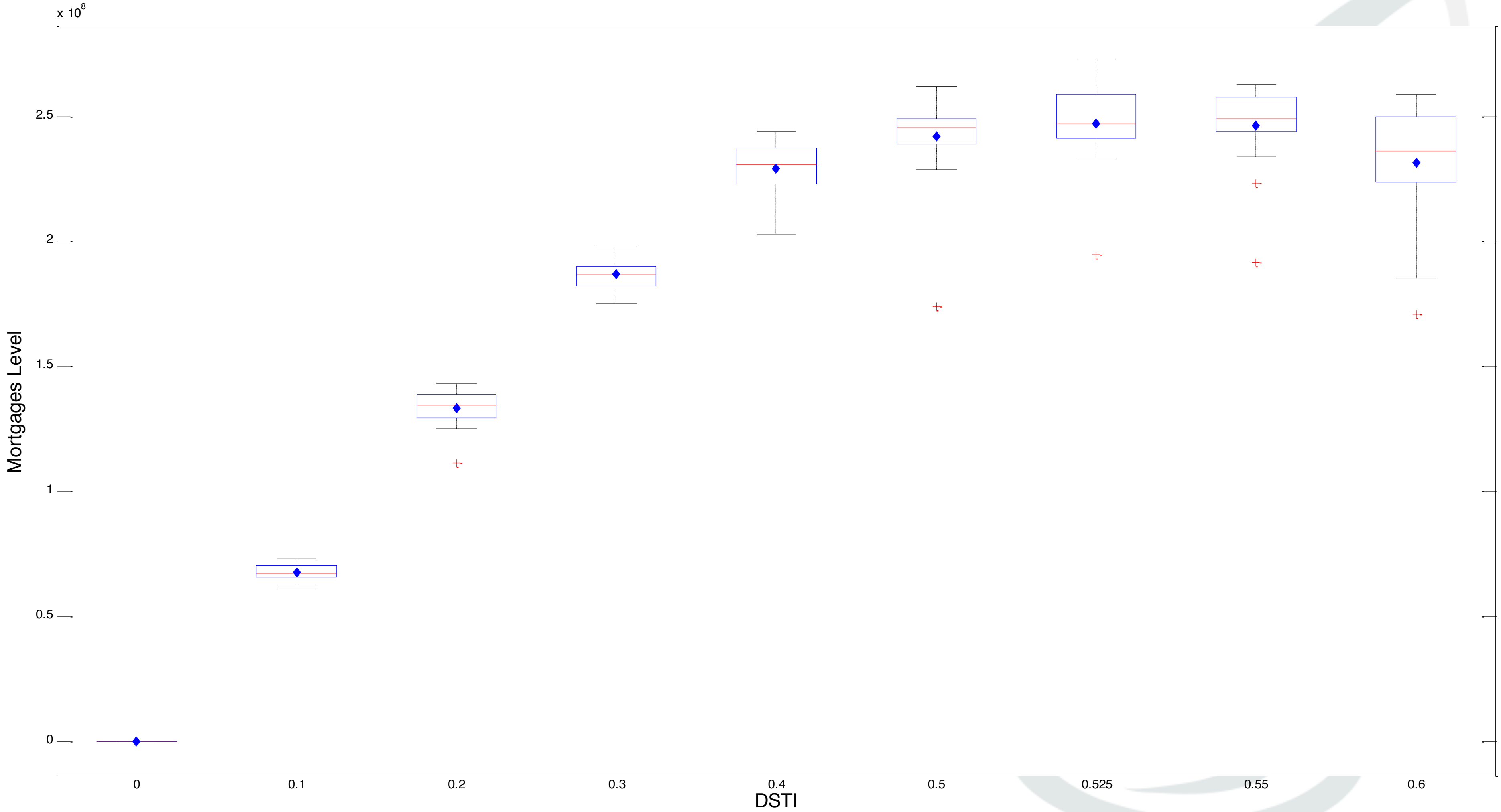
Computational experiments

- 3,000 households, 50 CGPs, 3 banks, 1 KGP, 1 Gov, 1 CB
- we aim to study the effect on the housing market price and on the economy of the different mortgage lending regulations provisions for the DSTI.
- DSTI = 0 ÷ 0.6
- $\phi^{fs} = 0.6 \qquad \phi^{d} = 0.7$
- we present the results both as time series of the main economic variables related to 1 realization (seed) and as box plots over 20 realizations (seeds)

Loans and mortgages

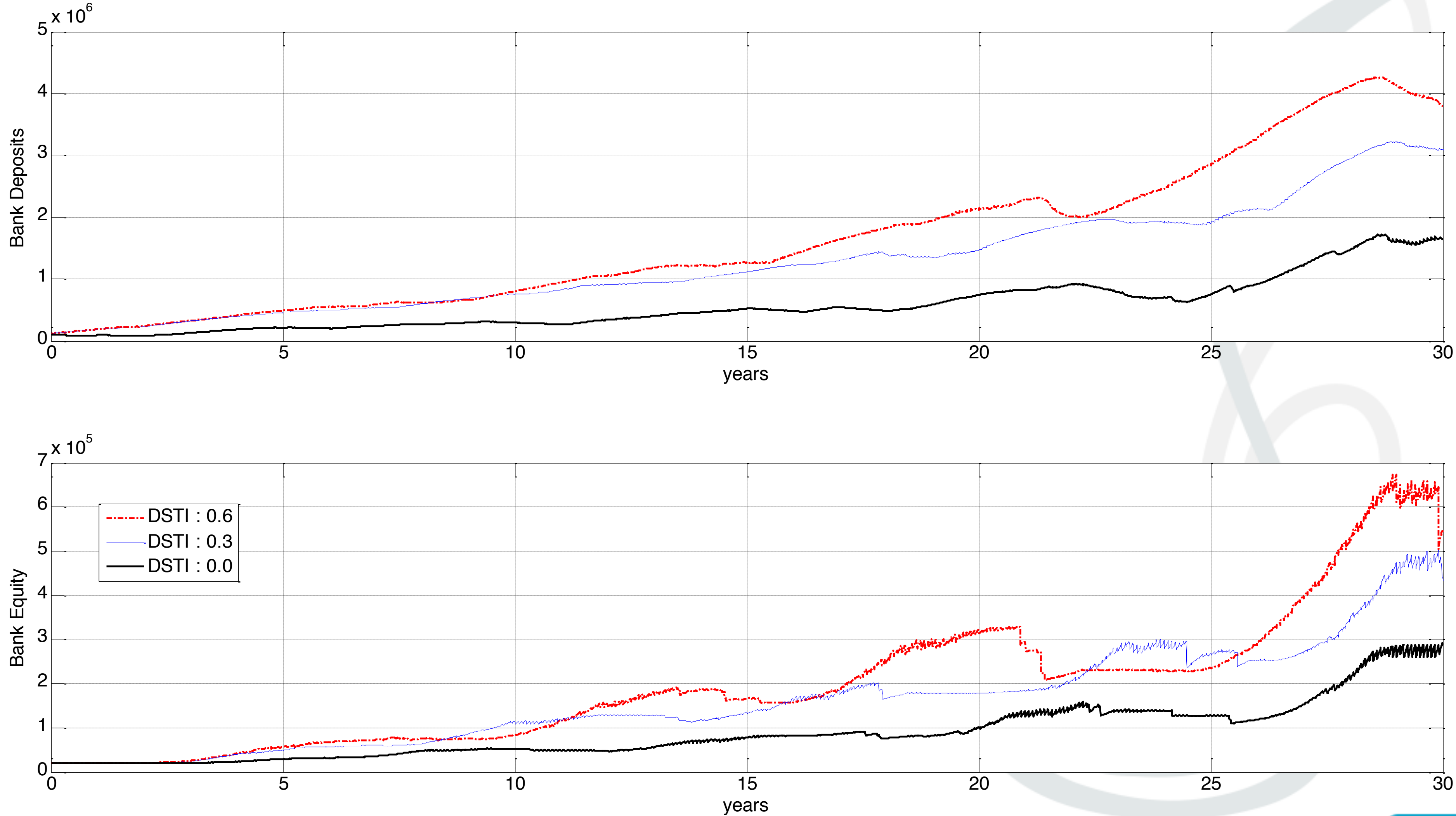


Mortgages

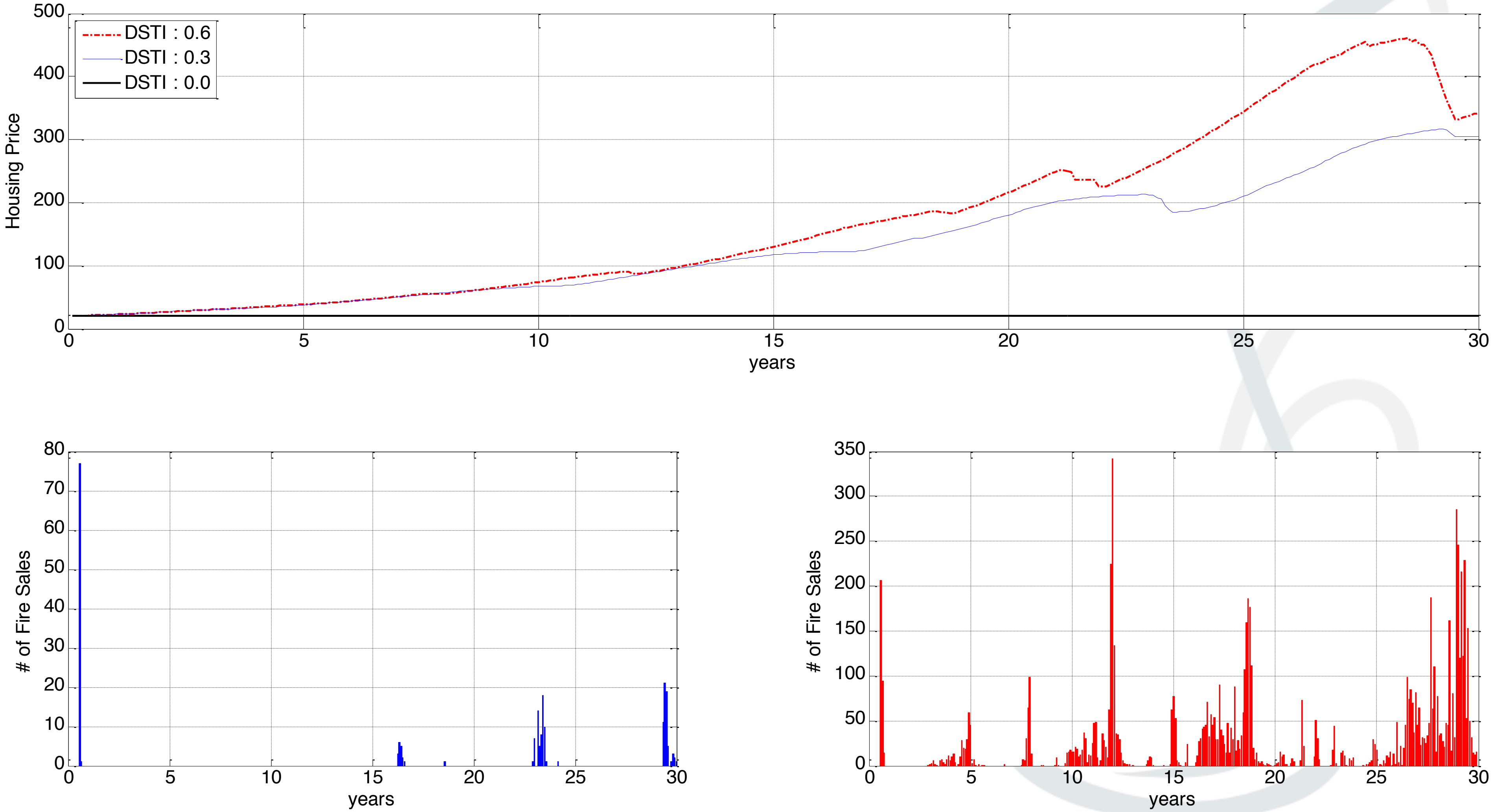


x 10^8
Mortgages Level
2.5
2
1.5
1
0.5
0
0
0.1
0.2
0.3
0.4
0.5
0.525
0.55
0.6
DSTI

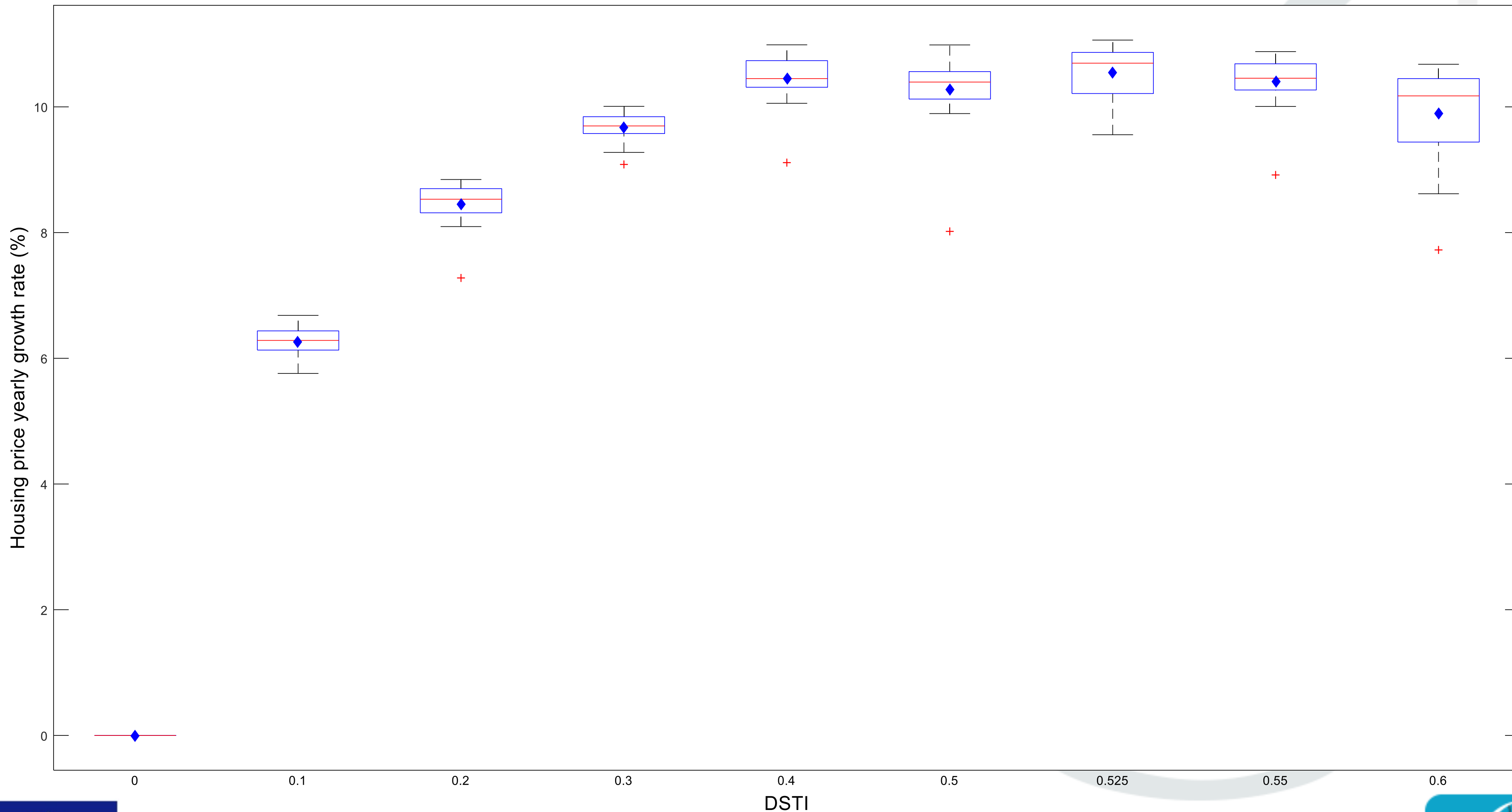
Banks' deposits and equity



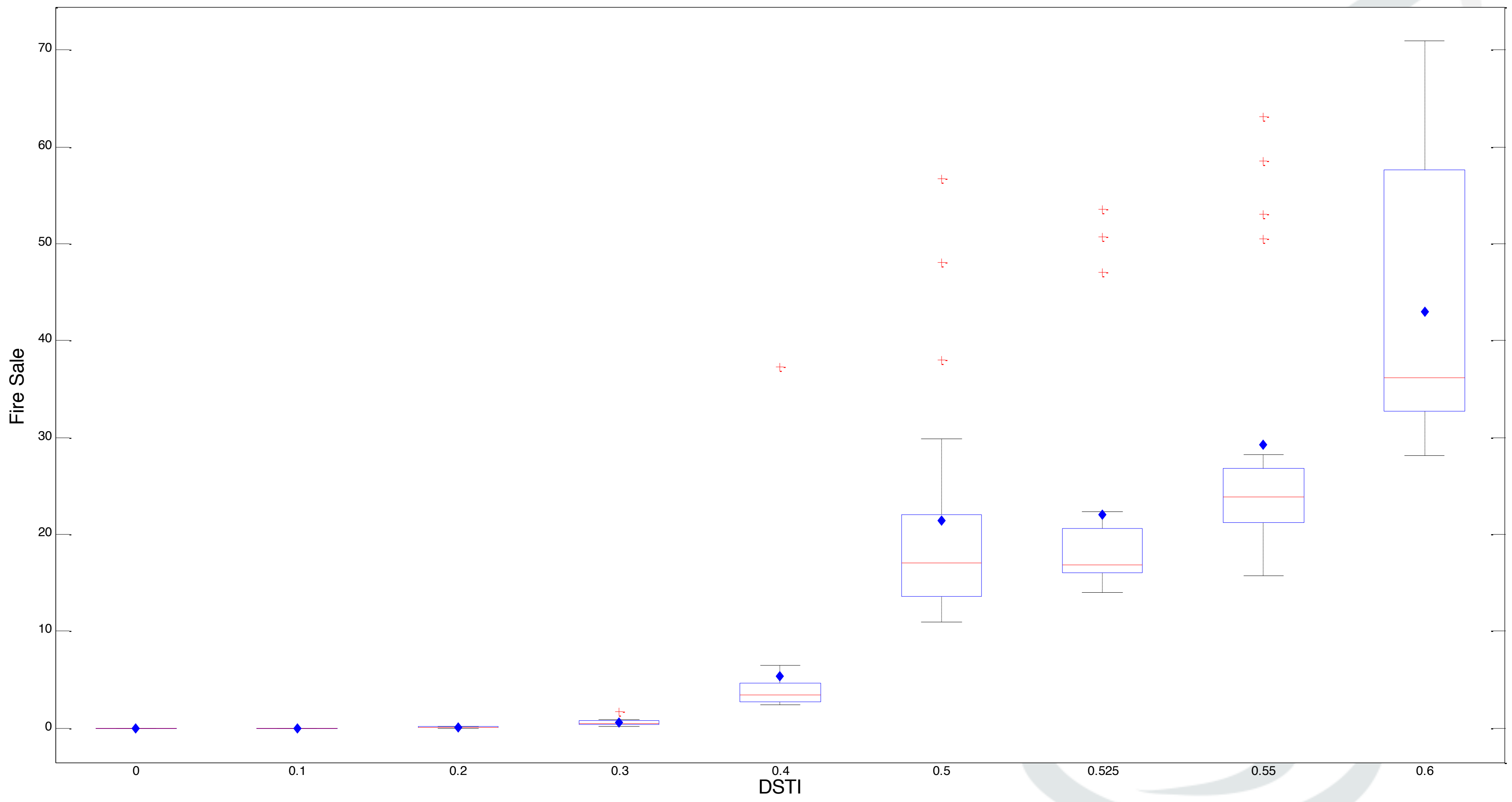
Housing price and fire sales



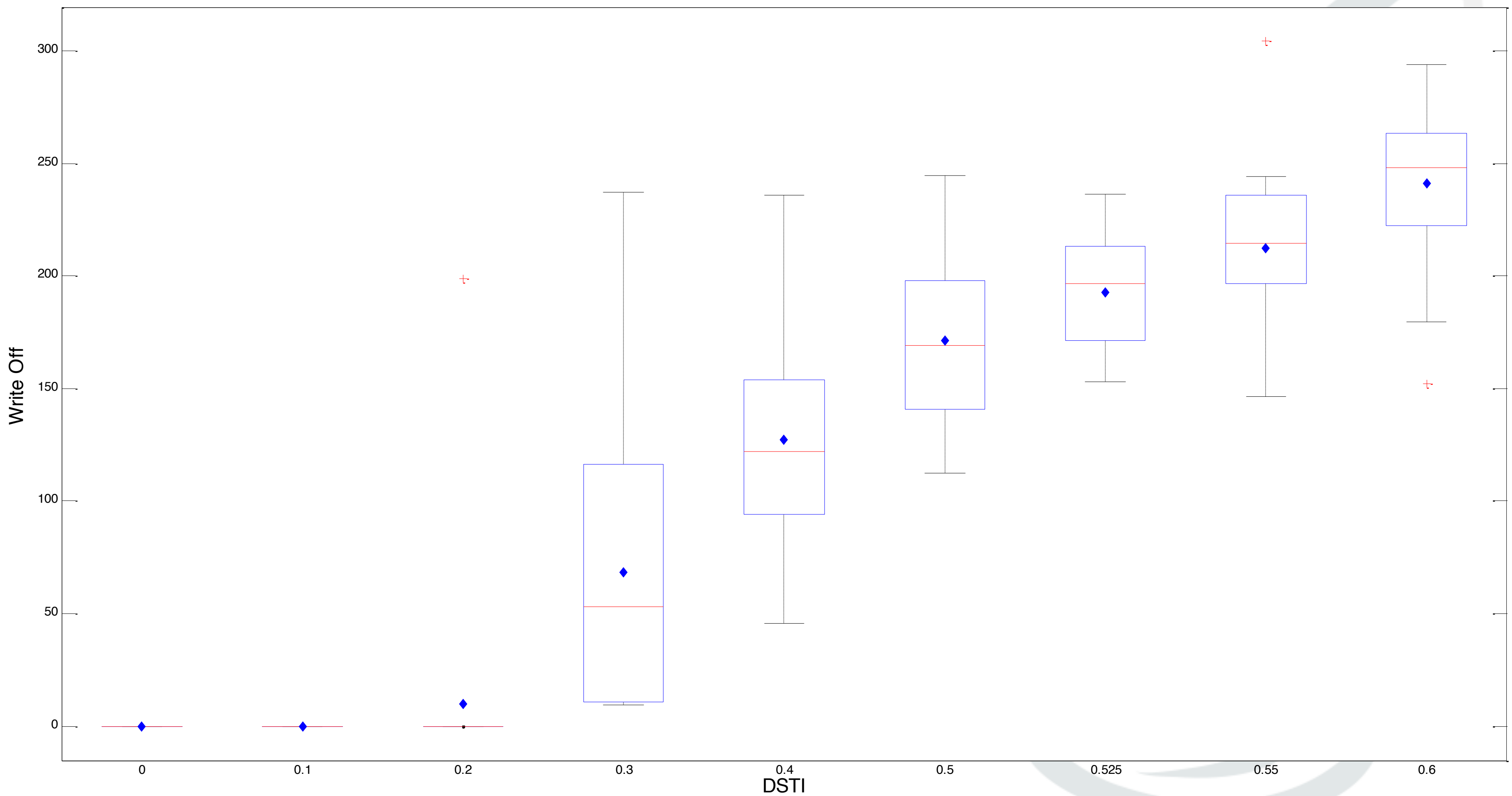
Housing price yearly growth rate (%)



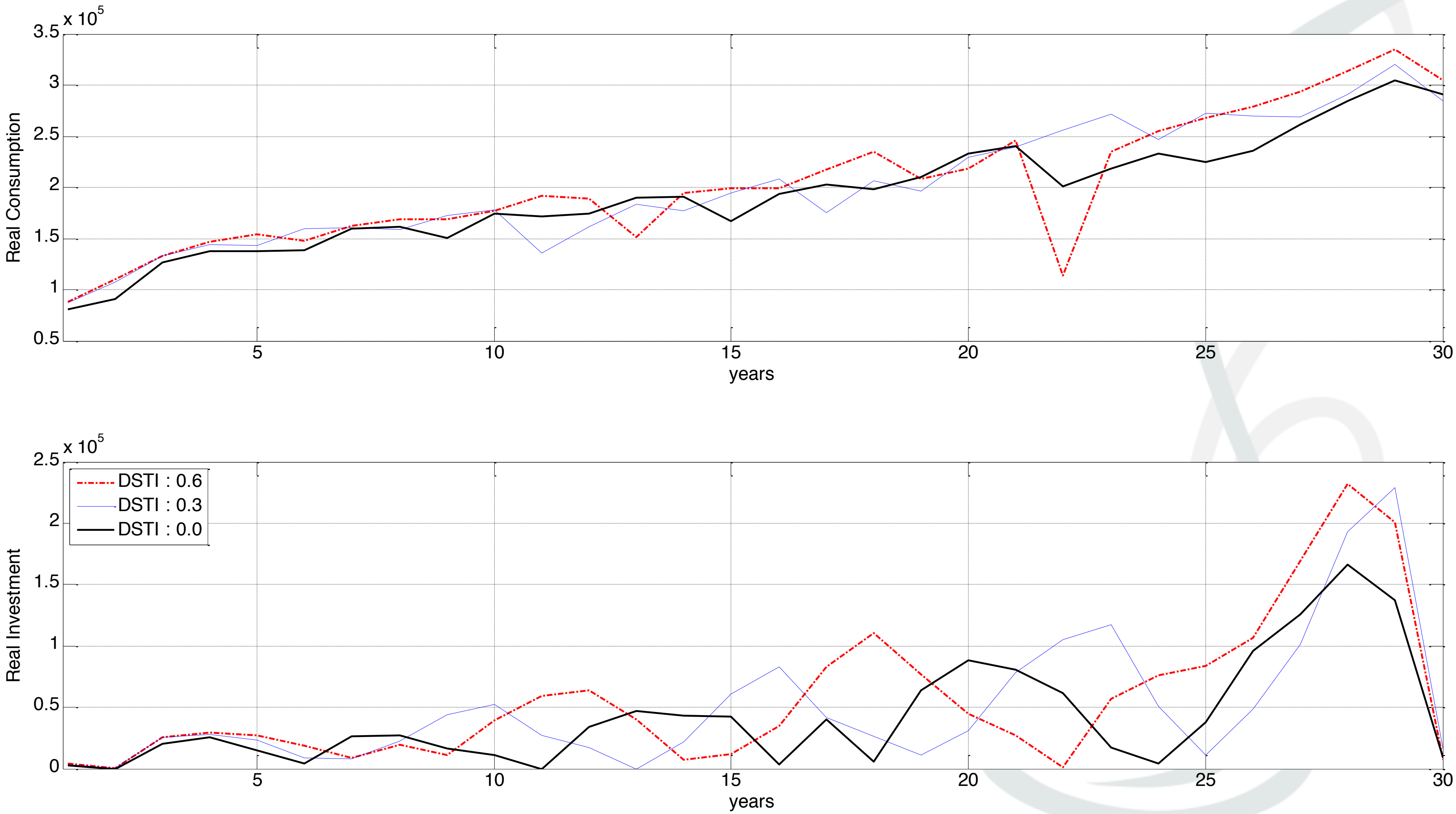
fire sales



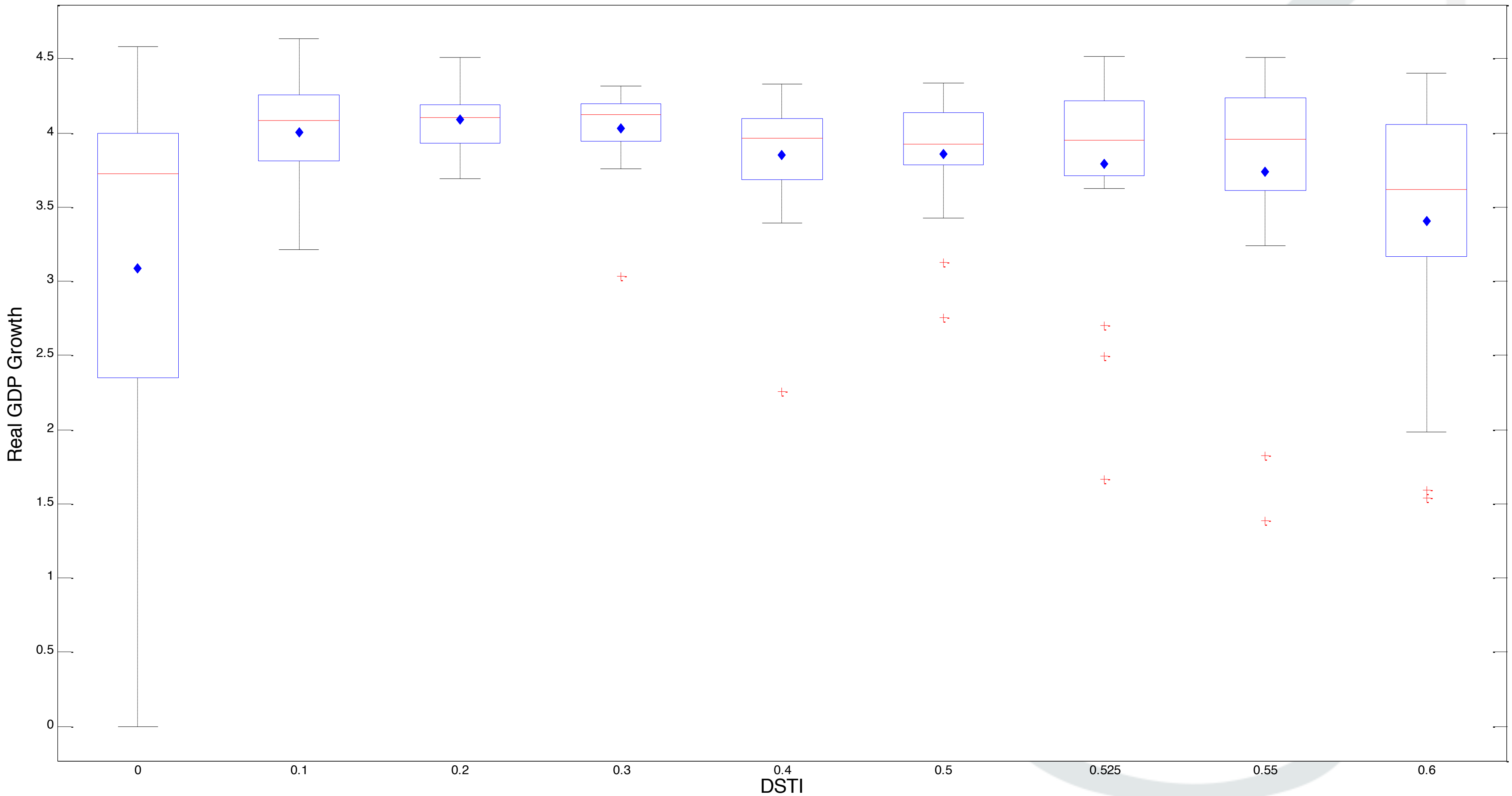
mortgages write-offs



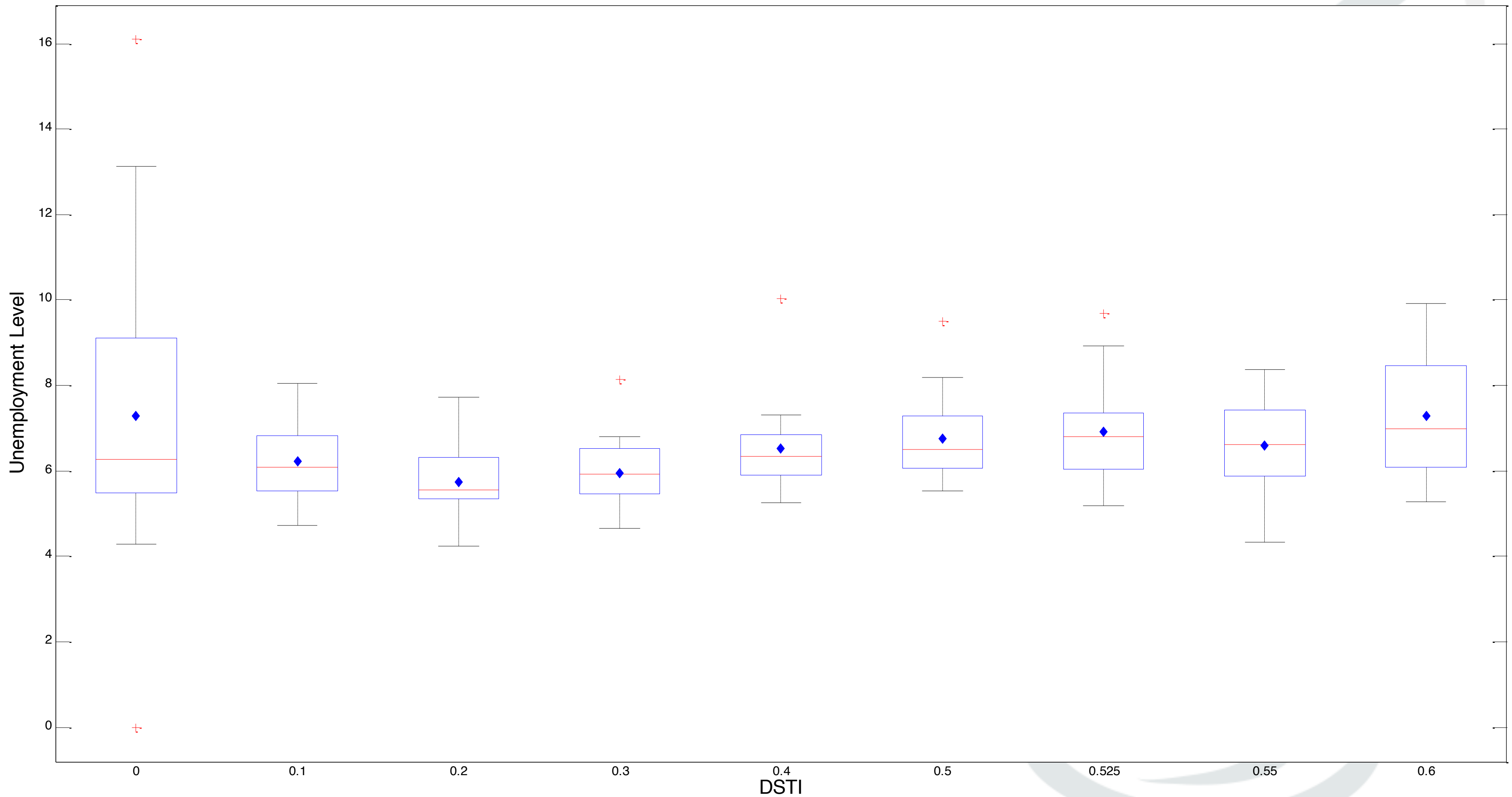
Real consumption and investments



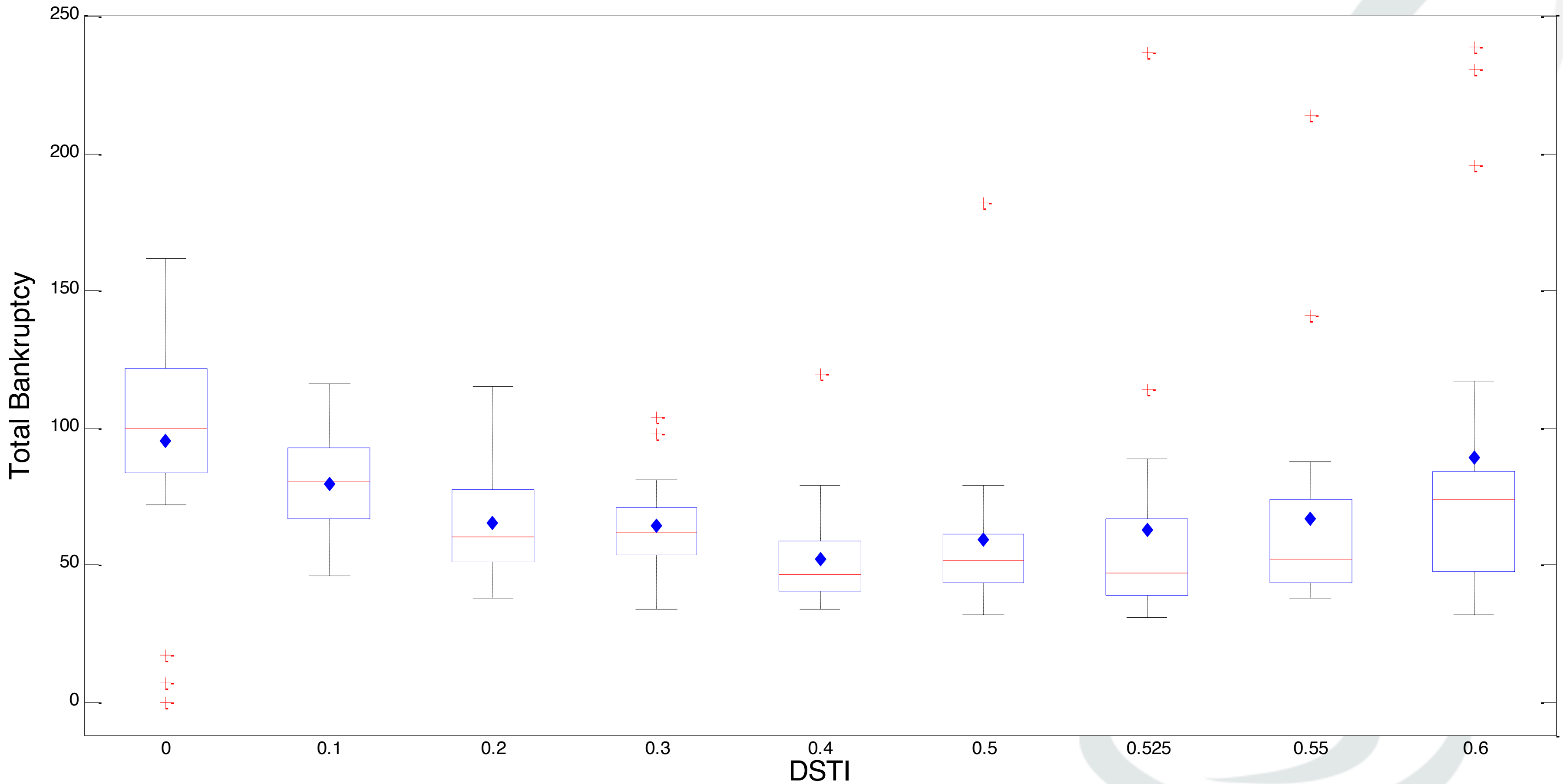
Real GDP growth rate (%)



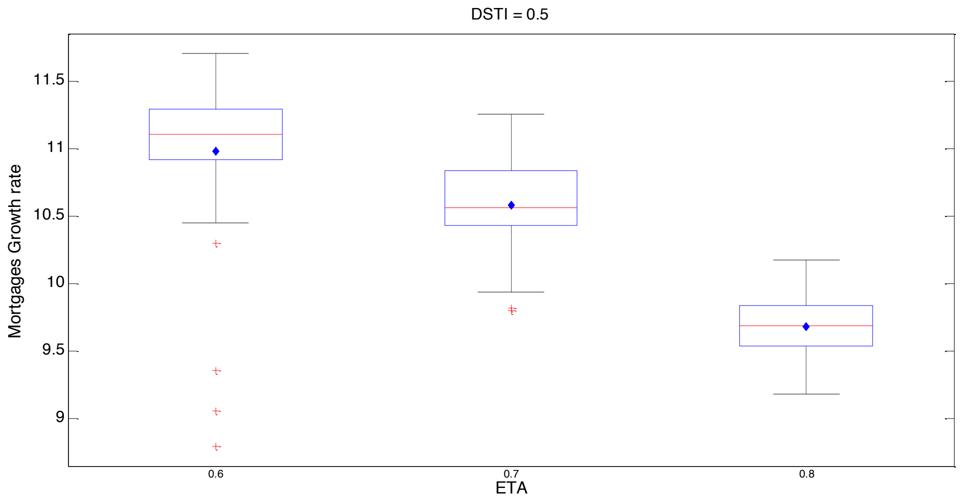
Unemployment rate (%)

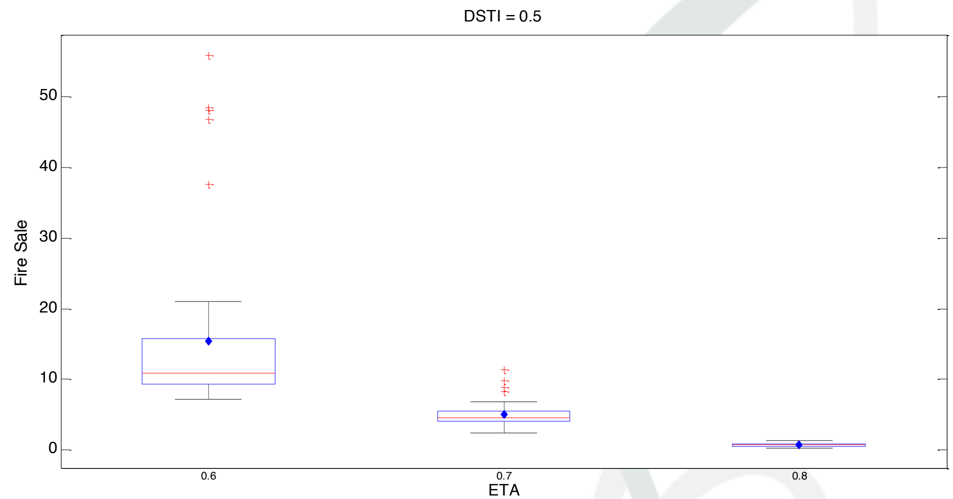


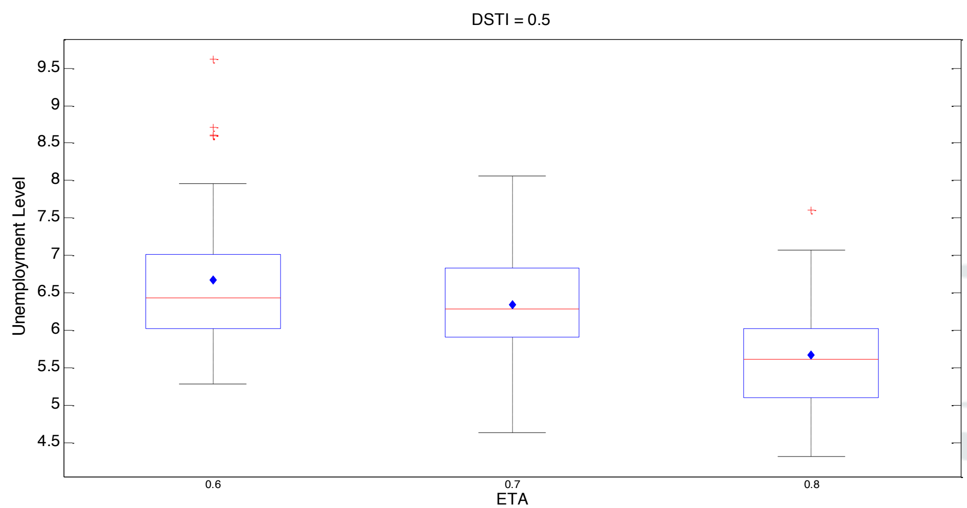
firms' bankruptcies



What happen if we control for the equity ratio of the borrower?



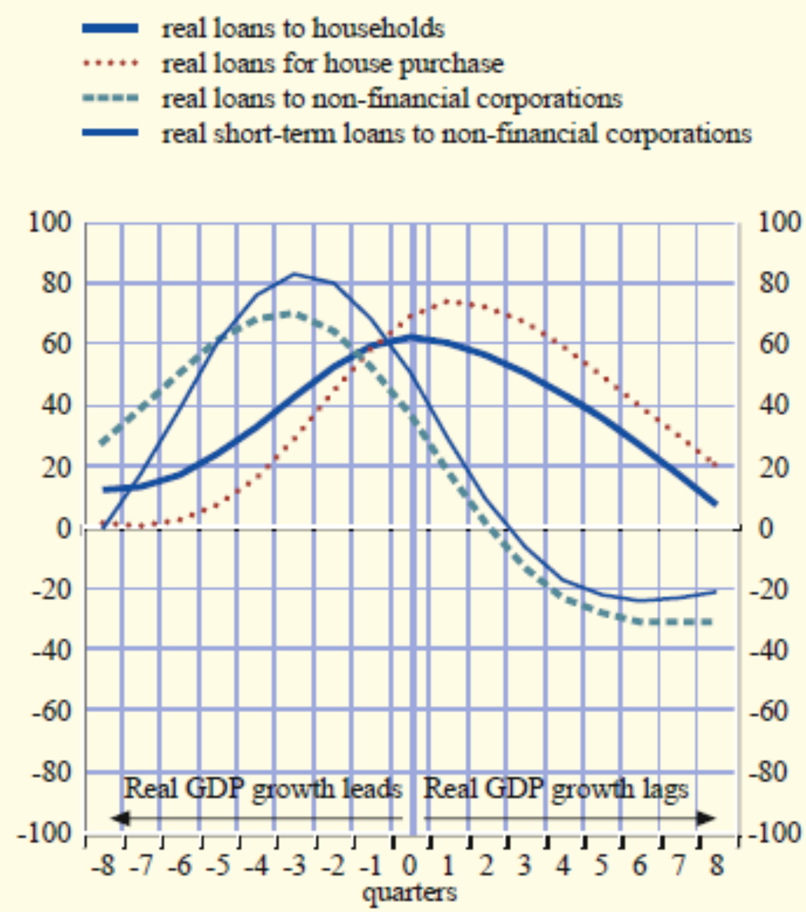




Eurozone data (ECB)

Chart D Correlation between real growth in household loans, real growth in non-financial corporation loans, sub-components of the two series, and real GDP growth for different leads/lags

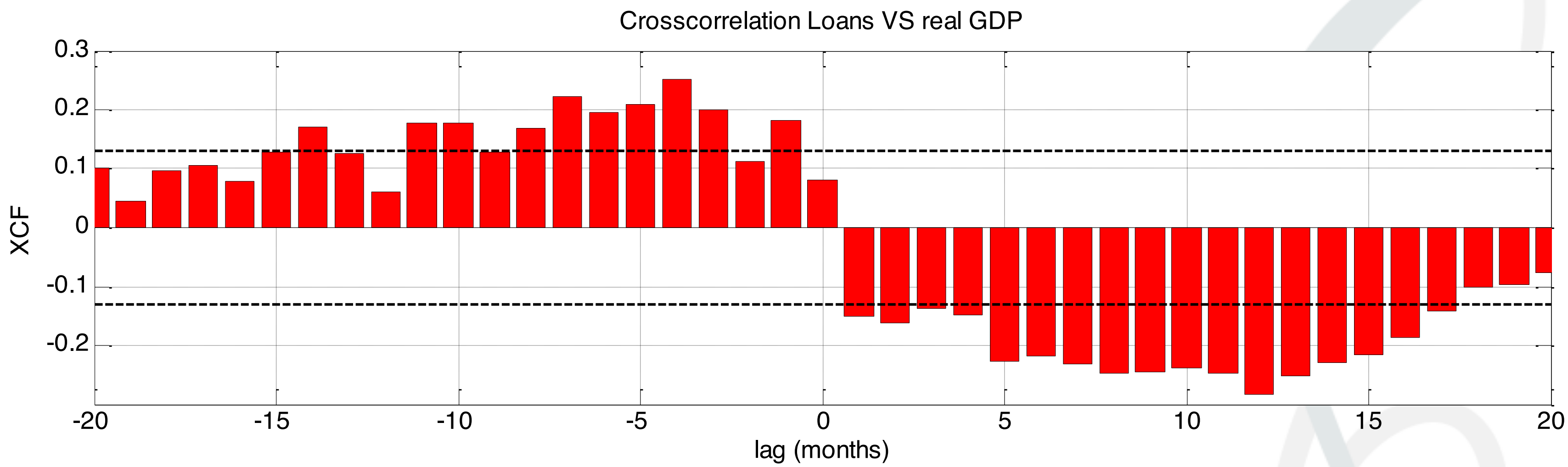
(correlation between annual percentage changes; percentages)

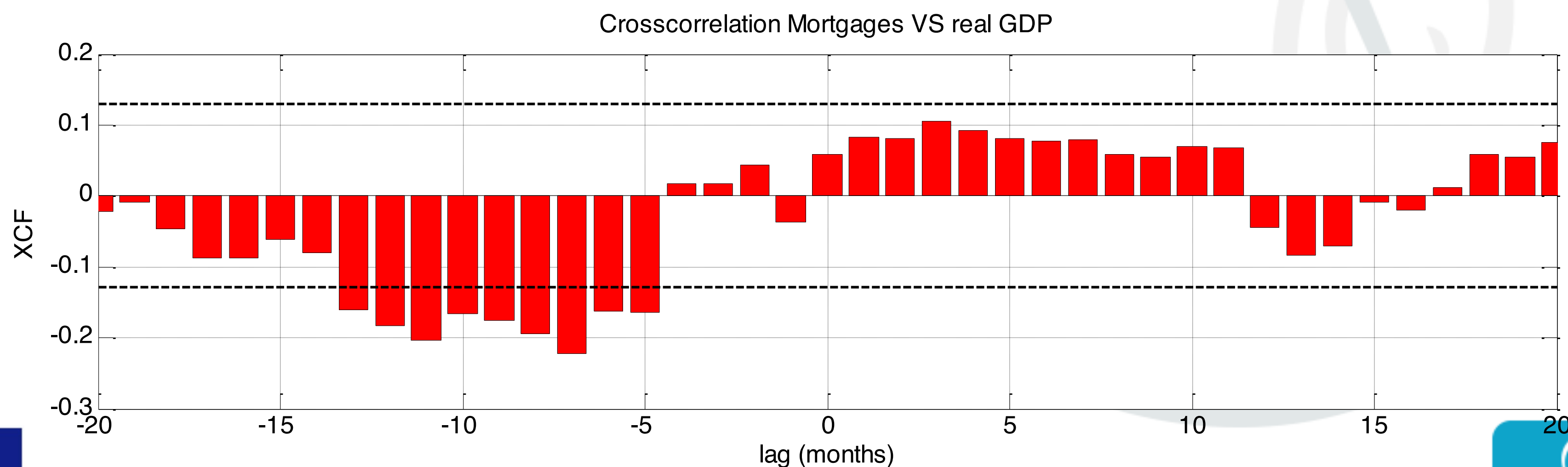


Sources: ECB, Eurostat and ECB calculations.
Notes: Data are for the period between the first quarter of 1990 and the second quarter of 2013. Real series have been derived by deflating nominal series with the GDP deflator.

ECB Monthly Bulletin, October 2013, p. 21

Crosscorrelations in Eurace





Remarks

- HM impacts both nominal and real variables through the endogenous money creation by the new mortgage loans that increase households bank deposits and in turn, stimulates consumption.
- Endogenous money and economic performance raise quickly and significantly for low values of DSTI (until 0.3 - 0.4), then becomes stable, and finally, after a threshold (around DSTI = 0.5), the economic performance deteriorates.
- This worsening is due to a higher instability of the economy when sub-prime borrowers have access to credit, increasing the number of housing units fire sales, bank write off and, finally, firms bankruptcies.

Overall conclusions

- Eurace has provided advances in the modeling of a realistic and complete macro-economy
- It is able to show the emergence of endogenous business cycles which are mainly due to the interplay between the real economic activity and its financing through the credit market
- It provides a computational facility where to perform "qualitative" what-if analyses and economic policy design
- **Ongoing work**:
  - Application to study the sustainability transition in the energy sector
  - Multi-country model
  - Calibration on the EU economy data

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