The Eurace framework: a research agenda for agent-based models and financial stability

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A snapshot of EURACE

- An overview about EURACE
- The balance-sheet approach
- A policy experiment about quantitative easing
- A research agenda about EURACE and AB models

Main objectives of EURACE

- Scientific objectives:
  - Establishing an innovative framework for the study of the macroeconomy according to the agent-based computational approach.
  - Providing new insights on the emergence of global regularities in the aggregation of heterogeneous interacting agents.
- Technological objective:
  - Development of new software methodologies for implementing, designing and validating large-scale agent-based economic simulations.
- Societal objective:
  - Development of an agent-based software platform to perform simulation experiments on economic policy design for the European Union.

A snapshot of EURACE

- The EURACE model represents a fully integrated macroeconomy 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** (polcy making, i.e., fiscal policy made by Governments and monetary policy set by the Central Bank).

Key features of EURACE

- Technology (FLAME, GUIs, parallelization).
- Spatial structure and local interactions.
- Realistic time scales and asynchronous interactions.
- Decentralized markets (Walrasian auctioneer banned expect 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.
- Validation based on the reproducibility of well-known empirical regularities and the consistency of balance sheets.

Agents (I)

The EURACE model is characterized by a set of agents' typologies with proper balance sheets and behavioral features:

- Households
- Consumption goods producing firms
- Investment goods producing firms
- Commercial Banks
- Governments
- Central bank

Agents (II)

Besides the agents presented before, the simulator is populated by a number of agents for the purpose of facilitating market exchanges and statistical computation:

- Malls
- Eurostat
- Clearing House

Markets

- Consumption goods market
- Investment goods market
- Credit market
- Financial market (stock and government bonds)
- Labor market

Except for the financial market, the other markets are all decentralized.

Examples 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 Planing
- 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.

Monetary and financial assets

- cash holdings in the form of commercial bank or central bank deposits. There is no cash hoarding since all money is held inside the banking sector;
- bank loans
- central bank standing facility
- government bonds
- equity shares (issued by firms and banks)

Real assets

- firms inventories
- physical capital
- human capital

Household (H): balance sheet overview

Assets	**Liabilities**
M^h: liquidity deposited at a given *bank*	
n_g^h: government bonds holdings	(nome)
n_f^h, n_b^h: equity shares holdings of firm f and bank b	

- Financial wealth:

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

- 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 *bank*	D_b^f: debts to *banks*
I_m^f: inventories at *malls*	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 *central bank*	D^b: standing facility (debts to the *central bank*)
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
gold (?)	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.

Validation rules

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

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

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

$$n^g = \sum_h n_g^h$$

Monetary aggregates and invariants

- In the EURACE model we have a key monetary invariant:

$$\Delta\Big(\sum_h M^h + \sum_f M^f\Big) + \Delta\Big(\sum_b E^b\Big) + \Delta\Big(\sum_g M^g + M^c\Big)$$

private sector deposits + banks' equity + public sector deposits

$$=$$

$$\Delta\Big(M^c + \sum_b L^c_b + QE\Big) + \Delta\Big(\sum_b \sum_f L^b_f\Big)$$

fiat money + credit money

Monetary aggregates and policy considerations

- For policy considerations, it is clearly important to consider the monetary endowment of agents in the private sector, i.e.,

$$\sum_h M^h + \sum_f M^f + \sum_b E^b$$

- An higher monetary endowment due, e.g., to a loose fiscal policy and QE, leads to a higher nominal demand that not necessarily translates into a higher real demand. It depends on the behavior of prices.

Policy experiments

- The computational experiments aims to investigate the overall performance of the EURACE economy with respect to two different and alternative fiscal and monetary policies:
  - fiscal tightening policy (FT)
  - quantitative easing policy (QE)
- The results may provide insights for designing suitable policies in the European economic scenario, where monetary authorities are implementing quantitative easing monetary policies.

Overview of the two policies

- Fiscal tightening policy (FT)
  - it pursues a zero government budget deficit objective by increasing tax rates if necessary.
  - the budget deficit, if any, is funded by both the increase of taxes and the issue of new government bonds which are sold in the market.

- Quantitative easing policy (QE)
  - the zero government budget deficit is NOT an issue. Tax rates are then maintained at a low constant level.
  - the budget deficit, if any, is funded just by the issue of new government bonds which are sold directly in the secondary market.
  - The Central Bank participate in the secondary bond market to buy an amount of gov bonds equal to the new issue.

Government budget items

- Revenues:
  - taxes on corporate profits and household labor and capital income
- Expenses:
  - unemployment benefits
  - Interests on debt

Note:

- we define government liquidity as the cumulated budget surplus
- the government bond is an infinite maturity bond with constant coupon

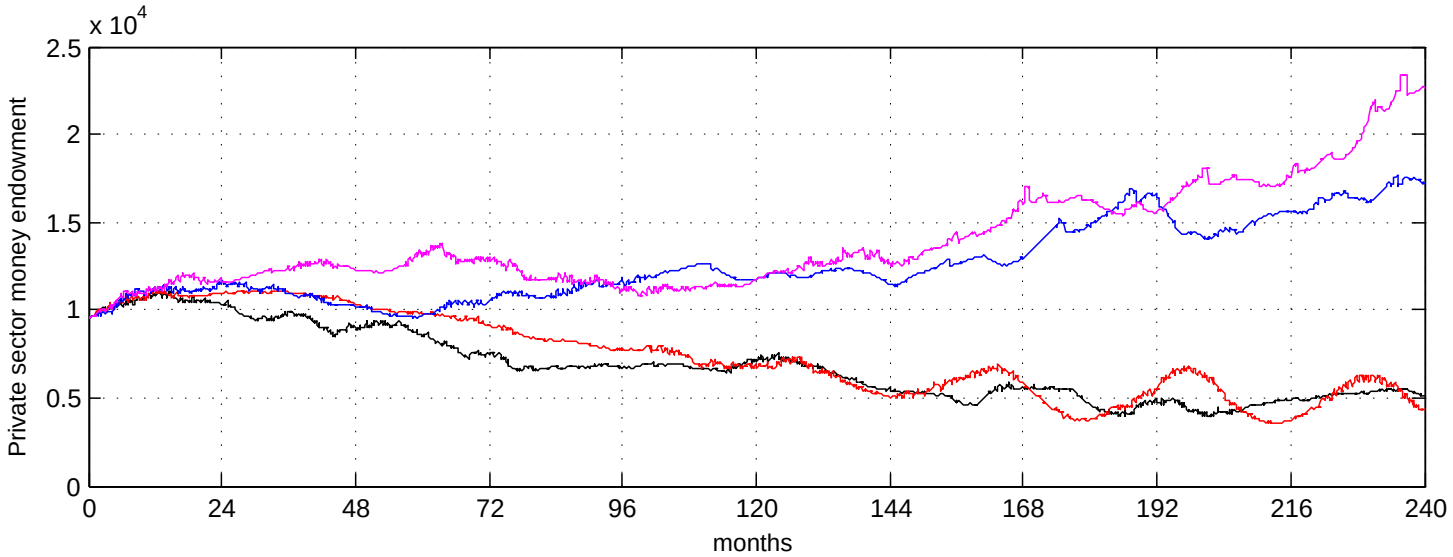
Policy actions

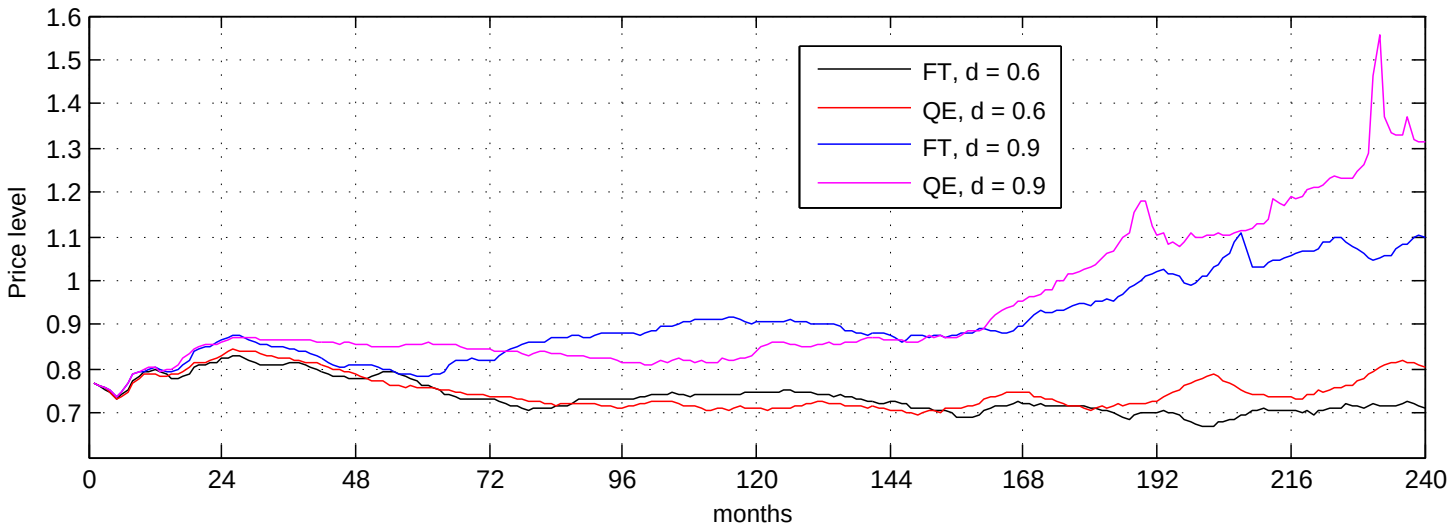
- FT policy:
  - the government raises the tax rates on a yearly basis if its present liquidity summed to past year budget deficit is negative.
- Both FT and QE policies:
  - the government issues new bonds on a monthly basis to increase its liquidity if negative.
- QE policy:
  - the central bank buys government bonds in the secondary market. Therefore, new money (fiat money) is created from nothing and injected into the economy.

Computational setting

- 1000 households, 10 firms, 2 banks
- 20 years of simulation
- Different levels of firms financial fragility have been considered by fixing exogenously the ratio (d) of earnings that firms pay out as dividends

Key nominal variables





d	policy	Private sector money endowment growth rate (%)	price inflation rate (%)	wage inflation rate (%)
0.5	FT	-0.47 (0.03)	-0.052 (0.004)	0.012 (0.001)
	QE	-0.39 (0.02)	-0.020 (0.007)	0.052 (0.009)
0.6	FT	-0.37 (0.02)	-0.048 (0.004)	0.008 (0.001)
	QE	-0.33 (0.03)	0.02 (0.01)	0.11 (0.02)
0.7	FT	-0.29 (0.02)	-0.038 (0.004)	0.016 (0.004)
	QE	-0.24 (0.03)	0.02 (0.01)	0.10 (0.02)
0.8	FT	-0.14 (0.03)	-0.011 (0.008)	0.036 (0.008)
	QE	-0.10 (0.03)	0.03 (0.01)	0.07 (0.02)
0.9	FT	0.16 (0.03)	0.11 (0.02)	0.13 (0.02)
	QE	0.18 (0.03)	0.14 (0.02)	0.16 (0.02)

Table: Ensemble averages (standard errors are in brackets) over 10 different simulation runs of mean monthly rates. Each run is characterized by a different random seed. For each simulation run, mean monthly rates are computed over the entire simulation period, except for the first 12 months which have been considered as a transient and

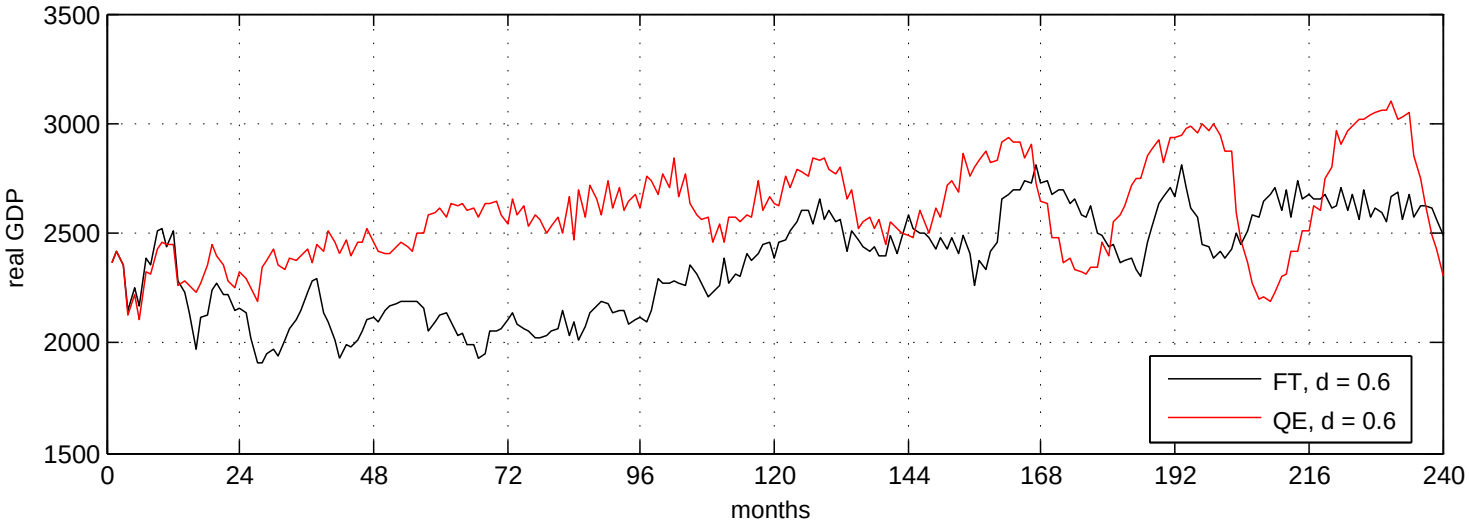
Remarks (I)

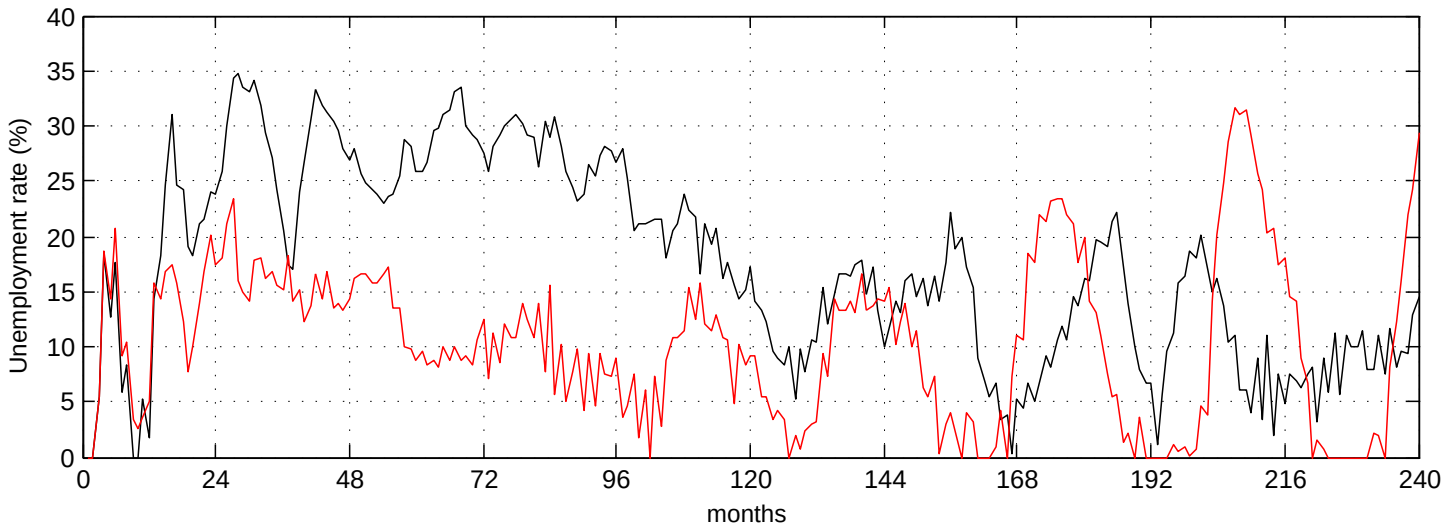
- The credit money supplied by the banking system is the source, together with the fiat money supplied by the central bank, of the endowment of liquid resources held by both the private sector (households, firms and banks) and the public sector (government and central bank).
- An increase (higher d) in the demand for credit by firms, if supplied by banks, then increases the amount of liquid resources in the economy.

Remarks (II)

- Higher inflation and wage rates are associated to higher values of d
- Higher inflation rates for higher values of d can not be directly explained according to the quantity theory of money, i.e. due to the higher amount of liquidity in the economy. This because prices are not set by a fictitious Walrasian auctioneer at the cross between demand and supply, but are set by firms, based on their costs, which are labor costs, capital costs and debt financing costs.
- Higher credit money means higher debt and higher debt financing costs, thus again higher price inflation through the cost channel.

Key real variables





d	policy	physical capital growth rate (%)	real GDP growth rate (%)	unemployment rate (%)
0.5	FT	0.140 (0.006)	0.023 (0.006)	20.3 (0.5)
	QE	0.19 (0.01)	0.052 (0.008)	10.68 (0.08)
0.6	FT	0.135 (0.006)	0.007 (0.01)	20.5 (0.8)
	QE	0.25 (0.02)	0.07 (0.02)	10.7 (0.1)
0.7	FT	0.157 (0.006)	0.036 (0.005)	19 (1)
	QE	0.25 (0.02)	0.07 (0.01)	10.4 (0.1)
0.8	FT	0.20 (0.01)	0.04 (0.01)	15.4 (0.6)
	QE	0.24 (0.02)	0.04 (0.02)	10.0 (0.1)
0.9	FT	0.28 (0.02)	0.06 (0.01)	13.2 (0.7)
	QE	0.29 (0.02)	0.05 (0.01)	8.5 (0.2)

Table: Ensemble averages (standard errors are in brackets) over 10 different simulation runs of mean monthly rates. Each run is characterized by a different random seed. For each simulation run, mean monthly rates are computed over the entire simulation period, except for the first 12 months which have been considered as a transient and discarded.

Remarks (I)

- The EURACE economy is able to reproduce endogenous short-term fluctuations (business cycles) as well as long-run growth
- Short-term fluctuations are caused by
  - coordination failure between demand and supply of consumption goods.
  - fluctuations in investment in physical capital
  - firms bankruptcies, i.e. disruptions in the supply chain
- Clear interdependence between fluctuations in real and monetary variables.
- Long-run growth is given by the growth of physical capital as well as labor productivity
- In the FT case, higher firms financial (higher d) clearly foster growth, while this is not so evident in the QE case..
- QE outperforms FT for low d.

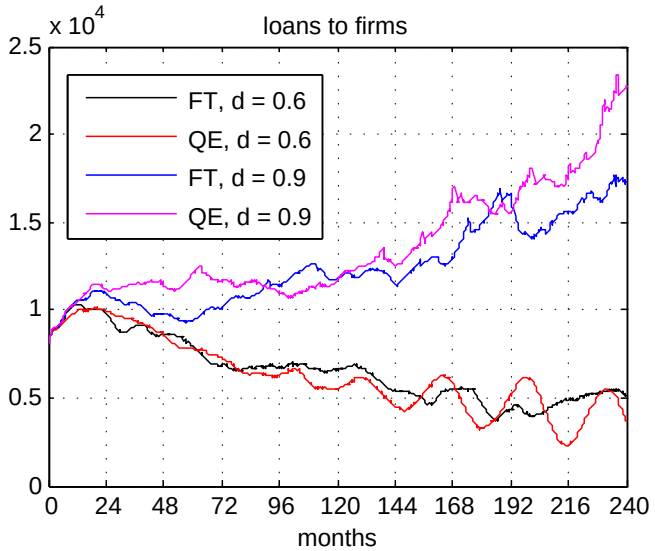
d	policy	lag -1	lag 0	lag 1
0.5	FT	0.00 (0.02)	0.50 (0.02)	0.42 (0.02)
	QE	0.24 (0.02)	0.30 (0.02)	0.37 (0.03)
0.6	FT	0.39 (0.02)	0.52 (0.01)	0.43 (0.01)
	QE	0.32 (0.02)	0.41 (0.02)	0.48 (0.03)
0.7	FT	0.39 (0.01)	0.52 (0.02)	0.45 (0.02)
	QE	0.31 (0.02)	0.43 (0.02)	0.49 (0.02)
0.8	FT	0.40 (0.02)	0.53 (0.02)	0.50 (0.03)
	QE	0.34 (0.03)	0.45 (0.03)	0.47 (0.05)
0.9	FT	0.19 (0.03)	0.30 (0.03)	0.39 (0.02)
	QE	0.18 (0.05)	0.27 (0.06)	0.36 (0.04)

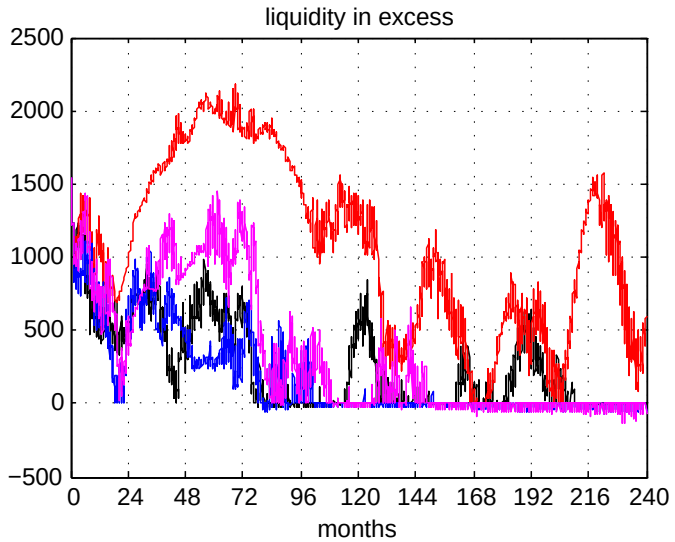
Table: Ensemble averages (standard errors are in brackets) over 10 different simulation runs of cross-correlations between percentages variations of the private sector money endowment and of the price level, respectively. High values al lag 1 are an indication that percentage variations of the private sector money endowment lead percentage variations of the price level.

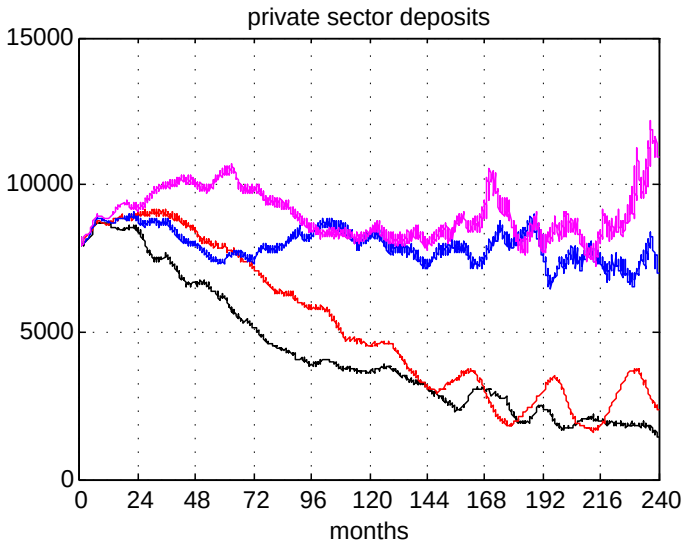
d	policy	lag -1	lag 0	lag 1
0.5	FT	0.21 (0.02)	0.20 (0.01)	0.06 (0.01)
	QE	0.22 (0.02)	0.01 (0.02)	0.15 (0.02)
0.6	FT	0.27 (0.02)	0.25 (0.01)	0.07 (0.01)
	QE	0.38 (0.04)	0.27 (0.03)	0.27 (0.05)
0.7	FT	0.28 (0.01)	0.27 (0.01)	0.10 (0.02)
	QE	0.38 (0.04)	0.29 (0.03)	0.26 (0.03)
0.8	FT	0.35 (0.02)	0.27 (0.02)	0.13 (0.02)
	QE	0.34 (0.04)	0.27 (0.03)	0.17 (0.03)
0.9	FT	0.34 (0.03)	0.31 (0.02)	0.14 (0.02)
	QE	0.31 (0.03)	0.26 (0.03)	0.10 (0.02)

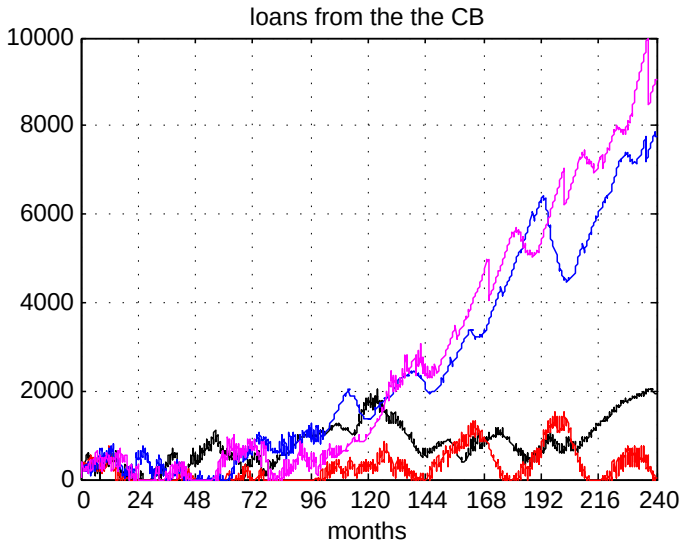
Table: Ensemble averages (standard errors are in brackets) over 10 different simulation runs of cross-correlations between percentages variations of the private sector money endowment and of the GDP, respectively. High values al lag -1 are an indication that percentage variations of GDP lead percentage variations of the private sector money endowment.

Banks data

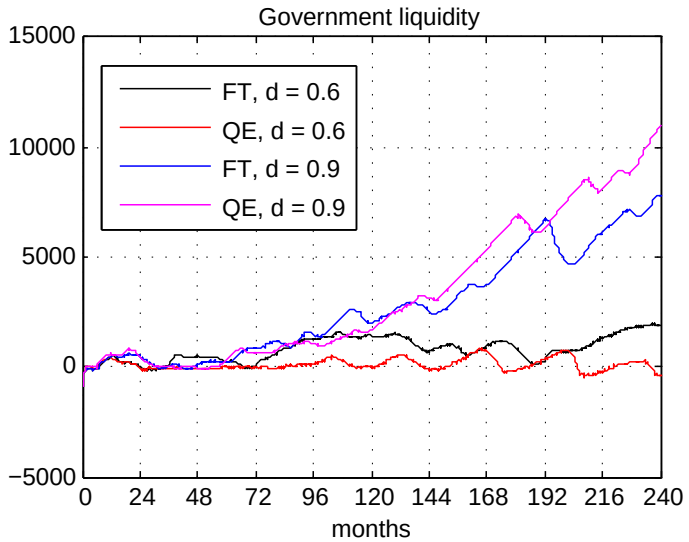

x 10^4
loans to firms
FT, d = 0.6
QE, d = 0.6
FT, d = 0.9
QE, d = 0.9
2.5
2
1.5
1
0.5
0
0 24 48 72 96 120 144 168 192 216 240
months

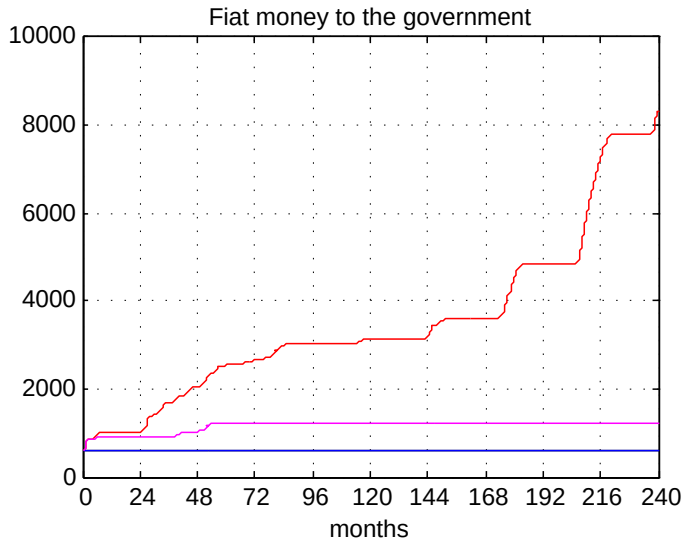

liquidity in excess
2500
2000
1500
1000
500
0
−500
0 24 48 72 96 120 144 168 192 216 240
months

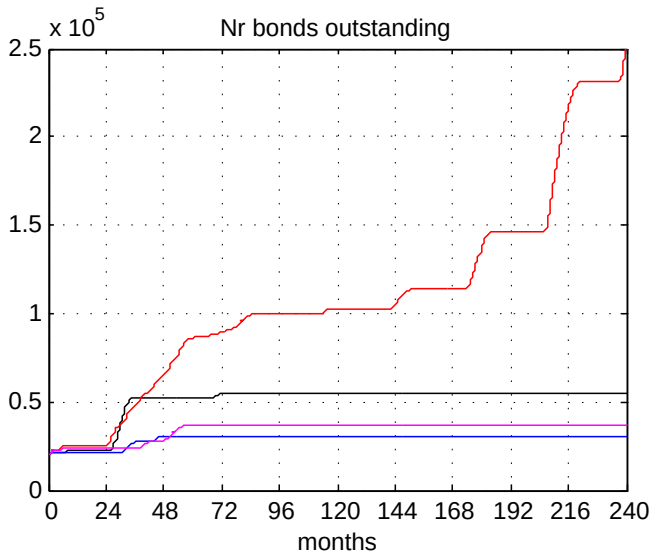

private sector deposits
15000
10000
5000
0
0 24 48 72 96 120 144 168 192 216 240
months

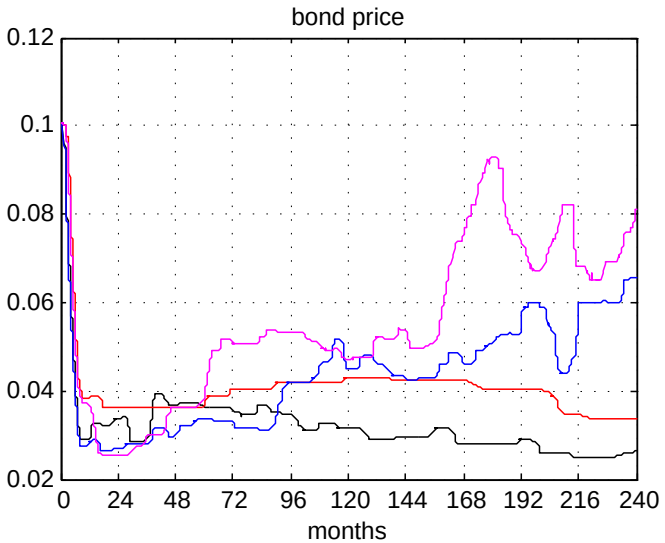

loans from the the CB
10000
8000
6000
4000
2000
0
0 24 48 72 96 120 144 168 192 216 240
months

Government data









Conclusions

- The EURACE economy shows endogenous business cycles and long-run growth
- Interdependence between real and nominal variables even in the long-run
- Firms financial fragility, firms bankruptcies and the credit channel are at the heart of this interdependence
- Policy outcomes:
  - low values of d (financial fragility of firms is low given that they mostly use internal funding to finance their investments)
    QE policy seems able to improve real economic performance
  - high values of d
    QE and FT policies give indistinguishable real outcomes
    Thi probably because of the high level of credit money in the economy that may act as a substitute of the central bank fiat money of the QE case

A research agenda for EURACE and general AB models

- From a modeling perspective:
  - Pay attention first more to structural aspects (e.g. stock-flow consistency, network topology, market microstructural properties) than behavioral ones.
  - Develop manageable analytical mean-field approximation by means of combinatorial stochastic processes, master equation techniques, in the spirit of Aoki and Yoshikawa (2007), Garibaldi and Scalas (2010).

- From a technological perspective: the choice of the right software platform is crucial. The software platform should be flexible (changes should be easy to make without jeopardizing quality), possibly OOP, and ready to be executed on cluster PC. Software engineering approaches needed: e.g., pair programming, testing first.