Comparison of the Current Monetary System and the Full Reserve System by Agent-based Models

János Zoltán Varga[1]

[1]University of Szeged, Faculty of Economics and Business Administration, Szeged
vjz@eco.u-szeged.hu

Abstract. Financial crises events trigger numerous regulatory responses and give rise to proposals with the aim to reduce the vulnerability of the financial sector. One direction of the proposals has been the limitation of credit and money creation power of commercial banks. The mentioned proposals were about to give the right to create money exclusively to the government or to other public monetary authority. In this study two agent-based models are designed in order to compare the different monetary regimes. Results: the current monetary system is unstable and the banks' perception about the economy's future prospect is crucial, but has the potential to allocate the resources optimally, while a central authority cannot have all the information required to allocate the resources so well, and performs suboptimal, but in a much more stable way. Moreover, the study proposed a possible way whereby the mainstream quantitative macroeconomic modeling technique, the DSGE approach can be supplemented by agent-based models in order to capture the complex features of economy.

Keywords: Simulation and Modeling. Banks. Evolutionary Algorithm. Credit. Exchange Equation.

1 Introduction

After the recent economic crisis, triggered by financial turmoil in 2007-2009, the fragility of the financial sector has returned to center stage in recent economic debates and discussions. It became obvious again that this sector is not neutral, its problems can affect seriously the real economy, can cause disturbances which result in falling output and wages, rising unemployment, poverty and inequality (see, e.g., [1]) and the recovery can be a painfully long process. The estimated costs of the crisis and its aftermath – i.e. the cumulative loss in output - in the USA and European Union can be as high as one year's national output [2, 3].

Financial crisis is a broad concept; one useful definition can be the following: „Crises are, at a certain level, extreme manifestation of the interactions between the financial sector and the real economy" [4]. The literature has classified crises into 4 types: currency crisis, sudden stops, foreign and domestic debt crisis, and banking crisis [4]. Despite the differences, they share common elements, such as asset price booms and credit booms. An asset price boom occurs when the asset prices (real estate prices, equity prices) climb up constantly for a longer period and these price movements cannot be explained by fundamental causes. However, without credit boom, asset price increases do not seem to have far reaching effects, do not induce large output losses [5], moreover, credit booms often precede asset price bubbles [6], currency crisis, sudden stops, banking crisis [7]. Besides, recessions (i.e. periods with negative GDP growth rate for at least two subsequent quarters) tend to be deeper and longer when they associate with financial crisis [8,9,10].

Naturally, crises events triggered numerous regulatory responses [11, 12] and gave rise to several proposals with the aim to reduce the vulnerability of the financial sector. One direction of the proposals has been the limitation of credit and money creation power of commercial banks. In the current financial system, commercial banks and the central bank together create credit and hitherto money, while the commercial banks create the majority of money. The mentioned proposals were about to give the right to create money exclusively to the government or to other public monetary authority.[1]

2 Banking System

We have seen in the previous section that credit boom plays an important role in financial crises and recessions. Thus, it is worth to overview the process of how the credit is created and who creates it.

The existence of financial intermediaries is usually explained by the cost advantages that come from economies of scale and information economies of scope. However, banks are not mere intermediaries. Modern money always represents a debit-credit relationship between the owner and issuer of the money, i.e., a claim on the issuer. So, money is always an asset for somebody and a debt for somebody else. The „vast dense networks of overlapping and interconnected multilateral credit-debit relationship" [13:73] make it possible for the capitalist economy to function.

There are three main forms of money: cash, bank deposits and central bank reserves. Cash is issued by the central bank; bank deposits are issued by banks and central bank reserves is issued by the central bank. The holders of the latter are institutions which have an account at the central bank - usually the government and commercial banks. Cash and central bank reserves together are called central bank reserves.

Money supply or broad money refers to the sum of cash and bank deposits, although deposits make more than 90% of the money supply and advanced economies. Bank deposits are created when a bank extends a loan to a household or a company, simultaneously a new deposit is created with same amount. Thereby, vast majority of money is created by commercial banks. Similarly, a bank deposit and hence money is destructed when the loan is repaid [14,15,16].

The literature distinguishes four different types of constraints that an individual bank has to face in relation to credit creation – credit demand, liquidity, capital regulations and monetary policy [14],[16,17].

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[1] For an overview of the different proposals see [33], the current study do not wish to replicate any of them, however, the full-reserve model is loosely based on [34]. for an analysis of monetary policy in full-reserve system see [35].

At any given time households or companies demand for loan is needed. They have to perceive that their future income will make them be able to repay the loan, and the bank has to check their financial conditions. The bank's assessment of the borrower's ability to meet his or her financial obligations is based on norms of creditworthiness [13] (certainly, these norms involve mathematical tools) and on the bank's general perception and expectation about the future state of economy. However, inductive skepticism basically states that we cannot infer future events with certainty based on past experiences [18], thus bankers, analysts and other experts, who constitute an epistemic community with shared norms and beliefs [19], form expectations about the future partly unreasonable, that is, those expectations cannot be justified.

Only when their (i.e. the bank and the borrower) perceptions about the future and hence the borrowers financial position are in concordance with each other, should the loan be extended. So, what a bank thinks about the future of the economy is crucial and has a significant effect on its lending willingness, and risk taking behavior.

> There are a number of reasons why many banks may choose to increase their lending markedly at the same time. For example, the profitability of lending at given interest rates could increase because of a general improvement in economic conditions. Alternatively, banks may decide to lend more if they perceive the risks associated with making loans to households and companies to have fallen. [14:7]

The application of asymmetric information framework to credit markets showed that in this case the banks' expectations can lead to lower [20] or higher [21] investment level than the social optimal.

3 The Models

One could easily state that the economy and the financial systems are complex systems [22,23,24,25,26]. However, the most popular contemporary quantitative macroeconomic modeling techniques (the so-called DSGE models) cannot grasp these features (for a critique, see, e.g. [27,28]). For this reason, agent-based techniques are used here to model the different monetary systems. Two models have been implemented in order to compare the current monetary system's performance with the one with only state created money (full reserve system). In Appendix B, pseudo codes can be found for both models. Table 3 and 4 in Appendix A summarize the variables used in the models.

3.1 Current Monetary System

In order to keep the model simple, the real economy is exogenous; the values of potential GDP growth rate and inflation are generated by autoregressive time series.[2] However, depending on the banks behavior, the actual real GDP can be lower and the

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[2] The exogenous variables could be computed by other methods, such as DSGE models, whereby the two modeling approach could be connected.

price can be higher than what is exogenously computed, so in fact they serve as an upper and lower limit. Moreover, the data generating equations contain their lagged values, and this ensures that there is a feedback from the model to the data generating process.

Let us consider the potential GDP growth first.

$$\Delta Y_t = c_1 + p_1 \Delta Y_{t-1} + \varepsilon_1 \quad (1)$$

Where ΔY_t is the potential GDP growth rate at time t, c_1 constant, such that $c = 1.2$, p_1 parameter, such that $\beta = 0.6$, ε_1 random process with zero expected value, and constant variance ($\sigma^2 = 0.25$). The process is stationary with 3 mean. This can be viewed as the theoretical maximum (potential) for GDP growth determined by the real factors of the economy (plant, machinery, labor and the applied technology).

The autoregressive time series of price change is the following:

$$\Delta P_\mathrm{t} = \mathrm{c}_2 + \mathrm{p}_2 \Delta P_{t-1} + \mathrm{p}_3 \Delta Y_t + \varepsilon_2 \quad (2)$$

Where ΔP_t is the price change at time t, c_2 is constant, such that $c_2 = 0.1$, p_2 is constant, such that $p_2 = 0.6$, p_3 is constant, such that $p_3 = 0.2$, ε_2 is a random process with zero expected value and constant variance ($\sigma^2 = 0.04$). The process is stationary with 1.75 mean.

At the beginning of every period, the exogenous variables are computed. After having the demand for real GDP and the deflator, using a modified version of equation of exchange

$$C_p v = P Y_p \quad (3)$$

where C_p is the amount of credits, and p refers to 'potential', v is the velocity of money, and is assumed to be constant, P is the price level, Y_p is the real GDP (p again, refers to 'potential').

The required amount of credit can now be determined. Since the model represents a closed economy (i.e. no foreign transactions), and the credits are due to be repaid in the next period (so every loan is for one period only), the quantity of deposits (M) equals the quantity of credit: $M = C$. Thus, P_t and Y_t are known, Cp can be determined: $C = PY / v$.

The only direct constrain on credit creation that an individual bank faces is the level of capital [29], therefore the level of capital needs to be determined before the credit can be allocated. In the model it is assumed that the banks do not pay dividend to the owners, so the total amount of profit is added to their capital (in case of negative profit, this amount is deducted from the capital), and there are no operating costs. This means that the profit depends on the difference between the received interest on credits and the interest paid on deposits. Since lending is risky, not all the extended credit will be repaid, some loans become default, these are called non-performing loans (NPLs, henceforward) in the model.[3]

Several factors are recognized in the literature which can have a significant impact on the level of NPLs, such as GDP growth, interest rate, exchange rate changes [30,31] lagged NPLs (i.e. the level of NPLs in the previous period) [30]. The NPLs

[3] The financial regulators usually define NPLs as „loans that are more than 90 days past due" [31:8], however in the current model, the loans are due to be repaid in the next period.

are calculated for every individual bank using an autoregressive time series. The above mentioned variables are incorporated into the equation with the exception of exchange rate changes, since the models do not contain foreign transactions.

$$NPL_t = c_3 + \alpha_1 NPL_{t-1} + \alpha_2 \Delta Y_t + \alpha_3 IR_{t-1} + \varepsilon_3 \tag{4}$$

where NPL_t is the non-performing loan ratio at time t, c_3 is constant, α_1 is a parameter, NPL_{t-1} is the non-performing loan ratio at time t-1, α_2 is a parameter, ΔY_t is GDP growth at time t, α_3 is a parameter, IR_{t-1} is the interest rate on credits applied by the given bank at time *t-1* and ε_3 is a random variable with zero expected value and constant variance.

After having the NPL rate, the banks can calculate the profit, the Return on Equity (ROE – which will be used as a fitness function), and the level of capital. The latter will be increased or decreased by amount of profit. If the level of equity drops below or equals zero, the bank goes bankrupt. Its deposits are saved by the government and a new bank is created with this amount of deposits, and its equity comes from the other banks (so their deposits and reserves are decremented).

The banks set their interest rates and then the credit is allocated to them. The quantity of the credit that an individual bank can take out has to be lower or equal than 12.5 x Equity (because of the capital adequacy requirement – equity/credits -, which is 8%). The credit allocating mechanism is described in the next section.

Allocating credit – C The willingness of banks to create new credit depends on how they perceive the general riskiness of the economy – in the model it is captured by a probability which affects the quantity of the credit a given bank creates (lending willingness).

First, the banks are sorted by their interest rate; then their lending willingness is computed (insertion sorting is applied).

Lending willingness: for the sake of simplicity, a bank can view the economy's prospect as *normal* (with *p* probability), *good* or *bad*, both with (1 - p) / 2 probabilities. The normal scenario means that the *i*-th bank wants to maintain the capital adequacy ratio at 10.5% (so the maximum credit, C_i, would be in this case 9.5 x Equity), *bad* – 15.38% (C_i = 6.5 x Equity), good - 8% (C_i = 12.5 x Equity).

Then, starting with the bank with lowest interest (b_1) rate, and depending on its lending willingness, either 6.5 x *Capital* (*bad* - case) or 9.5 x *Capital* credit (*normal* - case) is allocated to it. And the quantity of credit derived from the exchange equation is decreased by that amount. After that, the credit is allocated to the bank with the second lowest interest rate in the same manner and so on.

As for banks with *good* lending willingness, since they are more confident of the future prospects of the economy, they increase their lending so that their capital adequacy ratio can drop to 8 percent. This credit is not derived from potential GDP demand, so the total credit created by banks can be bigger than the credit required for the potential GDP. Although, it won't affect GDP, only the price level. It should be noted that by this credit allocating mechanism, unproductive credit (for example, credit which finances consumption or financial activity) cannot crowd out productive (i.e. derived from potential GDP demand) credit. So, regardless of how much credit is created by the banks, the actual GDP cannot be higher than the potential GDP which was generated exogenously. However, should the banks fail to provide the necessary amount of credit, actual GDP can be lower than potential GDP.

Actual GDP The level of credit (the sum of the credit that the individual banks take out, C_a where the subscript a refers to 'actual' as opposed to 'potential') determines the actual GDP and GDP-deflator: if $C_a \leq C_p$, then

$$C_a v = PY_a \tag{5}$$

Where C_a stands for the actual amount of credit, P is the price level obtained from (3.2), and Y_a is the actual GDP. If $C_a \geq C_p$, then

$$C_a v = P_a Y \tag{6}$$

Where P_a is the actual price level, Y is the potential GDP obtained from (1).

3.2. Full Reserve System

In this system, the banks cannot create money, rather, they can either borrow government issued money from the treasury at low or zero interest rate (in the model it is a 0.8xinterest rate), and loan that money to economic agents or their equity can be loaned as well. So, every loan must be financed by equity or treasury credit. The banks still have to meet the capital adequacy ratio requirement, which is the same as in the current monetary system – i.e. 8 percent.

The deposits are fully backed by government money. Other than that, the behavior of banks is similar to that in the current monetary system. The potential GDP growth rate (ΔY) and deflator (ΔP) are calculated exactly the same way as in the Current Monetary System model. The required amount of deposits can be obtained afterwards.

$$M_p v = PY_p \tag{7}$$

where $M_p$stands for the required amount of deposits, p refers to 'potential', v velocity of money (constant), P is the price level, obtained from (2), Y_p is the potential GDP, obtained from (1).

The government sets the growth rate of the quantity of money using a modified version of the Friedman-rule (it states that the money supply should grow according to the real GDP growth rate):

$$M_t = M_{t-1}(1 + g_t)(1 + \pi_t) \tag{8}$$

Where M_t is the quantity of money that the government wants to achieve at time t, M_{t-1} is the quantity of money at time t-1, g_t is the expected GDP growth rate and π_t is the expected inflation rate. The government does not know the real GDP growth rate (ΔY_t) and inflation ex ante, rather it estimates them ($g_{t,}\, \pi_t$) using simple moving average methods. This explains why g_t and π_t appears in (8) instead of ΔY_t and ΔP_t.

The government can increase the quantity of money via loaning money to banks, or via open market transaction (i.e. repurchasing government bonds, buying corporate bonds, injecting money into money market funds, venture capital funds etc.)

or via direct payments to economic actors (households, companies). In the model the government prefers the first option, and uses the other two only when the banks don't/cannot allocate the necessary quantity of credit (in this case it is modeled simply as an increase in the deposits and in the budget deficit).

So, the government determines the quantity of money it wants to achieve from (8). If $M_t > M_{t-1}$, then the quantity of credit that the banks can obtain from the treasury is $M_t - M_{t-1}$. If they do not accept all the available credit the government simply increases the amount of deposits. The credit allocating mechanism is the same as in the case of current monetary system with the exception that the banks cannot create money, rather they are borrowing it from the government, and they cannot borrow more than that was determined by the government. It should be noted here, that the credit is still allocated to private entities (households, companies etc.) by banks, hence their expertise on credit rating, information gathering and monitoring process is still needed, the government do not decide to whom they should take the credit. Only the banks cannot decide the total quantity. Besides, economic actors still could borrow money even if they are rejected by banks. Private enterprises (for example financial funds) can lend money to them, just like in the current system, but that is a pure financial intermediary activity without money creation and that is not represented in the model.

On the other hand, if $M_t < M_{t-1}$, then the amount of deposits will be decreased by $M_{t-1} - M_t$, this can be done via, for example, extra taxation, or preferably, via government bond repurchasement. In the model it is simply implemented as a decrease in the level of deposits.

Using the exchange equation, the actual real GDP and deflator can be calculated. If $M_t \leq M_p$, then

$$M_t v = P Y_a \tag{9}$$

Where M_t stands for the actual amount of money, P is the price level obtained from (2), and Y_a is the actual real GDP. If $M_t > M_p$, then

$$M_t v = P_a Y_p \tag{10}$$

where P_a is the actual price level, Y_p is the potential GDP obtained from (1).

4. Simulation Results

There are two different simulation settings (Setting 1 and 2 respectively) for both monetary systems. In Setting 1, initially, the interest rates are set by banks randomly - uniform distribution with value (0..10). The economic perception is determined randomly too, with a given *p* probability for *normal-case*, the probability of both *good* and *bad* case is (1-p)/2. The banks try to maximize their return on equity value (ROE). Evolutionary algorithm is applied with truncation selection [32] - the poor performing banks copy the interest rates of the best performing banks (the worst 20 percent copy the best 20 percent's interest rate). Besides, with 1/n probability, where n is the number of banks, the interest rate changes randomly (mutation).

In the second setting, the poor performing banks copy not only the interest rates of the best performing banks, but their economic perception too. And this attribute too is subject to mutation with *1/b* probability, where *b* is the number of banks. Important to emphasize that the particular values of the outputs are less interesting, they certainly depend on the parameters and model settings, the general patterns what really matter. Table 3 and 4 in Appendix A summarize the variables used in the models.

In Setting 1 the current system is sensitive to the number of banks and to the probability of *normal-case*, while the full reserve system is very stable, albeit suboptimal. The performance of the full reserve system is independent of the number of banks or their economic perception. This does not come as a surprise, since in the model the government has the exclusive ability to set the quantity of money. However, the government does not know the steady state value of GDP-growth and inflation, rather it estimates it using a simple moving average method, and doing so it constantly makes some mistake, so it cannot achieve the theoretical best performance. The current system can reach the theoretical optimal state, and hence outperform the full reserve system, when p is very close to 100%. In the full reserve system, the average interest rate settles at a significantly higher level than in the current system. Figure 1 and 2 shows the data of current system and full-reserve system, respectively.

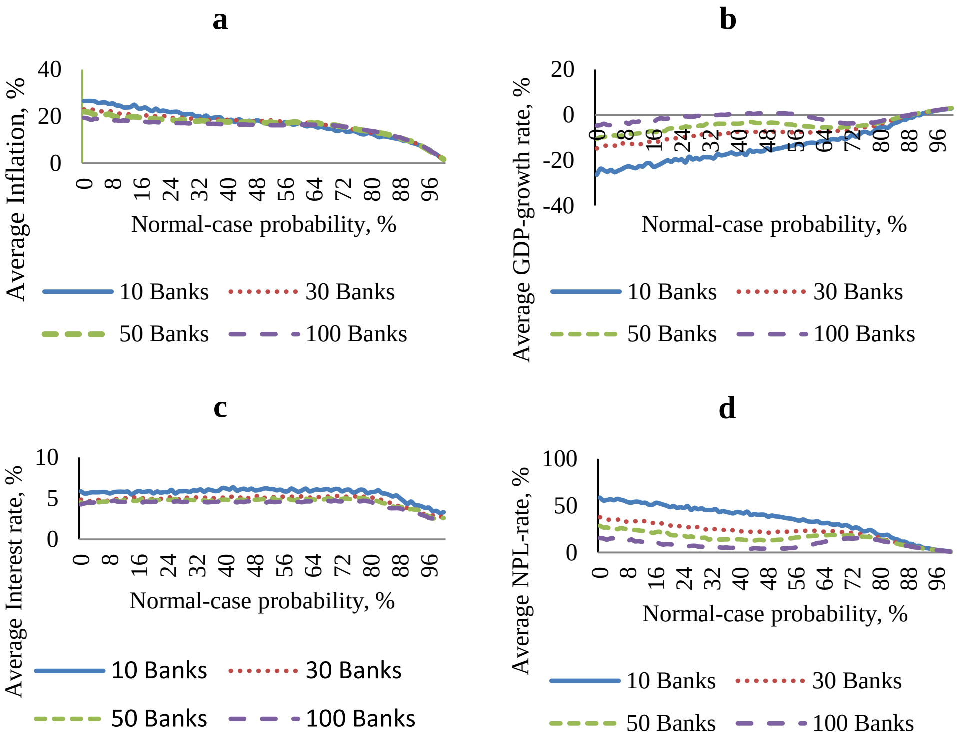

Fig. 1. Current monetary system, Setting 1 **a** Average inflation rate. **b** Average GDP-growth rate. **c** Average Interest rate. **d** Average NPL-rate.

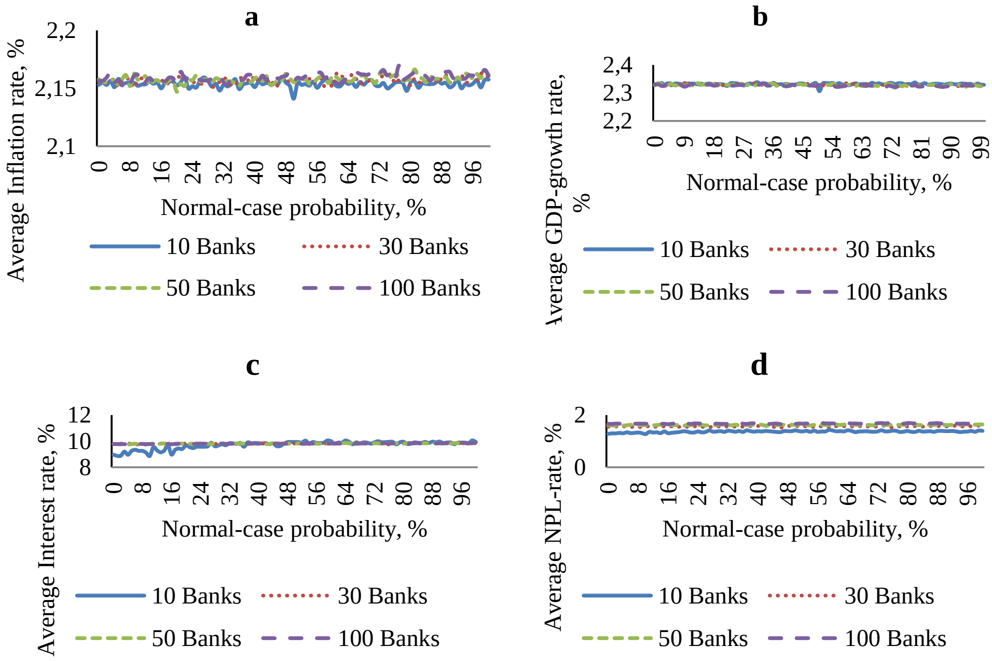

Fig. 2 Full-reserve system, Setting 1 **a** Average Inflation rate **b** Average GDP-growth rate. **c** Average Interest rate. **d** Average NPL-rate.

In Setting 2, the banks' perception in the current monetary system quickly converges to *good*, making it possible for them to constantly take out too much credit, causing much higher inflation than the steady state, but this also means that they can achieve the steady state GDP growth rate. They were able to improve their performance in terms of ROE. It is important to note that the excessive lending in real world economies entails asset price bubbles (as was elaborated in Introduction), which in turn can result in recessions. However, asset market is not explicitly modeled, so this feedback cannot appear in the output. The full reserve system's performance is about the same as in Setting 1, the government's control over money supply brings enormous stability at the cost of performing suboptimal.

The deposit rate (*deposit rate*) is the rate what is paid by banks after deposits, in the model it is proportional to the interest rate (*deposit rate = 0.8*interest rate*). It is worth to investigate the model's sensitivity to this coefficient. The current system was run with 50 banks and 3 different coefficients 0.2, 0.5, and 0.8, respectively, 100 times for every p value. As can be seen on figure 3, the general pattern does not change, however the exact values differ. This suggests that the model is qualitatively insensitive to this parameter.

Table 6 in Appendix summarizes the parameters used in Setting 2, table 1 and 2 summarize the results of Setting 2.

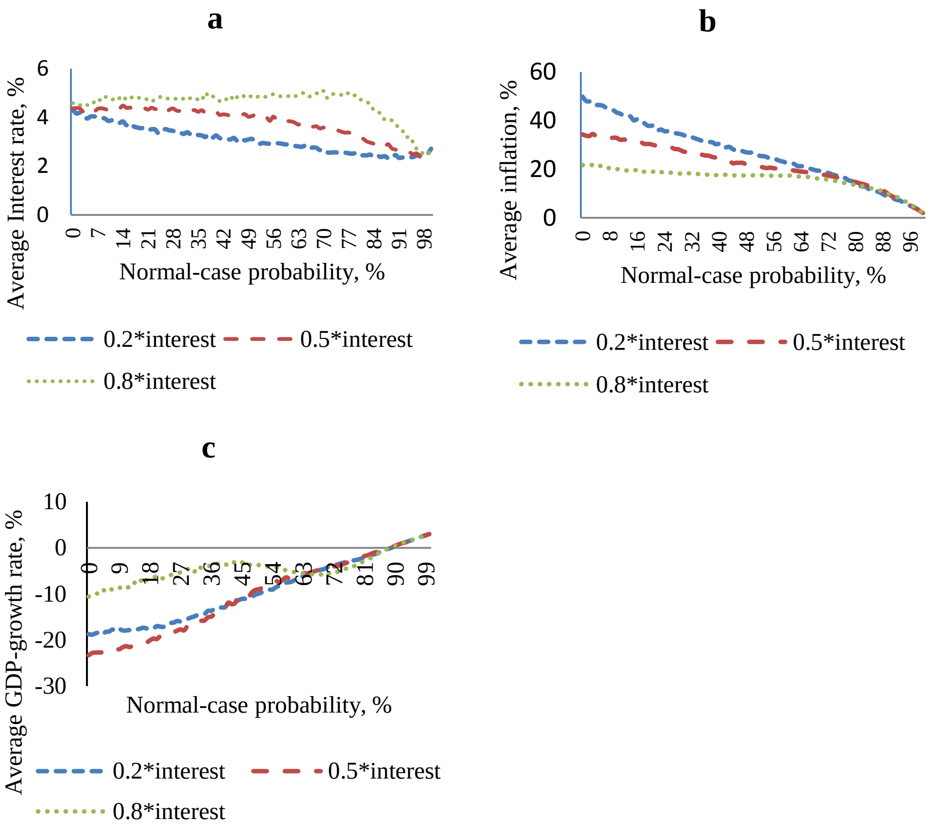

Fig. 3 Deposit rate sensitivity analysis

Table 1 Average values, Current Monetary System, Setting 2

Number of Banks	Inflation	GDP-growth	NPL	Interest rate	ROE
10	17,459	2,993	1,02	6,301	0,18
30	20,763	2,991	1,005	5,35	0,202
50	20,811	2,992	1,005	4,861	0,199
100	20,844	2,996	1,004	4,501	0,198

Table 2 Average values, Full Reserve System, Setting 2

Number of Banks	Inflation	GDP-growth	NPL	Interest rate	ROE
10	2,233	2,392	1,342	10,034	0,091
30	2,231	2,395	1,512	10,027	0,09

50	2,229	2,394	1,533	9,939	0,089
100	2,231	2,394	1,583	9,958	0,089

5. Conclusion

In this study, agent-based models have been designed to compare the current monetary system's performance with the one in which the money creating power belongs to the government. Despite the limitations of the models, they were able to demonstrate the usual arguments against both settings: namely, the current monetary system is unstable, and the banks' perception about the economy's future prospect is crucial, but has the potential to allocate the resources optimally, while a central authority cannot have all the information required to allocate the resources so well, and performs suboptimal, but in a much more stable way. Moreover, the study proposed a possible way whereby the mainstream quantitative macroeconomic modelling technique, the DSGE approach can be supplemented by agent-based models in order to capture the complex features of economy.

A Appendix

Table 3. Variables used in the current monetary system

Variable	Description
Y_p, Potential GDP	Generated by the time series, theoretical maximum (determined by level of the production factors and the technology)
Y_a, Actual GDP	Computed GDP by the model
P, Potential Price Level	Generated by the time series
P_a, Actual Price Level	Computed price level by the model
Lending willingness	The perception of a bank about the future prospect of economy (bad, normal, good). Determines the level of credit that the banks will take out
NPL	Nonperforming loan, default loan
Normal-case probability	The probability that an individual bank's future perception about the economy is normal - the bank then wants to maintain the capital adequacy ratio at 12.5%
C_p, Potential Credit	Credit demand for GDP transaction
C_a, Actual Credit	Quantity of credit computed by the model
v	Velocity of money

Table 4. Variables used in the full reserve system model

Variable	Description
Y_p, Potential GDP	Generated by the time series, theoretical maximum (determined by level of the production factors and the technology)
Y_a, Actual GDP	Computed GDP by the model
P, Potential Price Level	Generated by the time series
P_a, Actual Price Level	Computed price level by the model
Lending willingness	The perception of a bank about the future prospect of economy (*bad, normal, good*). Determines the level of credit that the banks will take out
NPL	Nonperforming loan, default loan
Normal-case probability	The probability that an individual bank's future perception about the economy is normal - the bank then wants to maintain the capital adequacy ratio at 12.5%
M_p, Required Money	Required quantity of money for potential GDP
M_e, Estimated Money	The required quantity of money estimated by the Government
v	Velocity of money
g	Estimated GDP-Growth Rate
π	Estimated Inflation rate

B Appendix

Pseudo code for the Current Monetary System Model

```
For each period
  calculate potential GDP change
  calculate price change
  for each banks
    calculate NPLs
    calculate Profit and Capital
    if (bank default) then create new bank
    determine Lending willingness
    determine interest rate
  sort banks by their interest rate
  allocate credit to banks
  calculate actual real GDP and price level
```

Pseudo code for the Full Reserve System Model

```
For each period
  calculate potential GDP change
  calculate price change
  government calculates the quantity of money it wants to
  achieve
  government calculates the quantity of credit that the
  banks can borrow
  for each banks
    calculate NPLs
    calculate Profit and Capital
    if (bank default) then create new bank
    determine Lending willingness
    determine interest rate
  sort banks by their interest rate
  allocate credit to banks
  if (banks do not take out all the available money) then
  the deposits are increased
  calculate actual GDP and price level
```

C Appendix

Table 5 Setting 1 parameters

Parameters	Value
Number of banks	10, 30, 50, 100
Periods	2000
Normal-case probability	1..100
Number of simulations per step	100
Steady state GDP growth rate	3
Steady state inflation rate	1.75
Fitness Function	**ROE**
Changing Attribute	Interest Rate

Table 6 Setting 2 parameters

Parameters	Value
Number of banks	10, 30, 50, 100
Periods	2000
Normal-case probability	1..100
Number of simulations per step	100
Steady state GDP growth rate	3

Steady state inflation rate	1.75
Fitness Function	**ROE**
Changing Attribute	Interest Rate, Perception

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