Agent-based model of banking system in Russia

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March 13, 2018

Abstract

The paper develops the analytical multi-agent model of the Russian banking system that identifies the source of systemic risk using modern approaches for assessing network effects. The model will allow solving the following objectives: (1) to offer an improved agent-based model as an alternative method for the banking system stress testing in response to the regulators’ concern about its robustness (the Bundesbank’s study, 2015); (2) to meet the regulators’ demand for a tool to design the financial stability policy $^1$; (3) to offer a model for building strategies in different markets, taking into account the strategy of the competing banks. Among the first results of the model, the lifetime of the system with negative margin was determined.

Keywords: banks; network effects; the interbank lending market; agent-based model; systemic risk; stress testing; assessing regulatory impacts.

JEL: G17, G21, G28, L14.

*Acknowledgement: The paper was prepared within the framework of the Basic Research Program at the National Research University Higher School of Economics (HSE) and supported within the framework of a subsidy by the Russian Academic Excellence Project ‘5–100’. The work was conducted by the International Laboratory of Decision Choice and Analysis (DeCAn Lab) and Department of Applied Economics of the National Research University Higher School of Economics and Laboratory of Mathematical Modeling of Complex Systems of P.N. Lebedev Physical Institute.

$^1$On 20 November 2017, the Bank of Russia hosted an international workshop on economic research entitled “Macroeconomic Models for Central Banks”. URL: https://www.cbr.ru/Press/event/?id=1499
1 Introduction

Agent-based models (hereafter - ABM) are realized as computer codes simulating economic or social interaction according to some specified protocol of heterogeneous economic agents. ABMs can be used both for checking theoretical hypotheses and studying the response of economic systems to regulatory changes. Development of a realistic ABM of the banking system is of significant importance for constructing realistic agent-based macroeconomic models, checking the consequences of regulatory innovations such as Basel Accords and providing a realistic analysis of macroeconomic and financial risk impact.

Incorporation of a realistic ABM of the banking system into macroeconomic models can help address the following major issues:

- **Stress-testing.** Ability to estimate the key characteristics such as the number and capitalization of surviving banks, etc., under various crisis scenarios. The description of scenarios can be probabilistic and include changes in such economic indicators as GDP, state and corporate bonds yields, stock market indices, an exchange rate of the national currency, oil and gold prices, etc. For each bank, the model should describe the corresponding evolution of its balance sheet and for the banking system as a whole - the changes in its risk pattern as seen through the lens of the Central Bank requirements for solvency, liquidity, concentration, etc. ABM is of use to trace procyclicality effects. Economic stagnation leads to deterioration in bank clients’ creditworthiness and their risk (estimates) evaluation (e.g. risk weights) fostering increases in risk-weighted assets (hereafter - RWA) all else being equal. It results in scrutinizing lending and further economic stagnation.

- **Impact of regulatory changes.** Ability to estimate the consequences of the regulatory changes imposed on the banking system such as, e.g., raising the prudential capital and liquidity minimal ratios, etc. The model should provide a detailed description of the state of individual banks in terms of various risk indicators. It also enables tracing the game theory realisation when regulators overestimate new raise in a requirement to have the option of dampening those. Banks then overassess new initiatives’ impact to demotivate its introduction. Thus, it is expected that requirements are raised much more than is optimal (e.g. Basel IV TLAC capital requirement is 18% of RWA where Basel II was only 2% of RWA, i.e. 9x higher what may seem to be exorbitant spike).

- **Strategic planning.** Ability to describe the strategies of banks in different markets taking into account the strategies of rival banks. The model should represent a realistic coupling between banking and industrial sectors. ABM allows decomposing rival responses at country and local, regional levels.

The paper is organized as follows. The next section 2 contains a literature review. Section 3 develops the model and presents the protocol by which agents interact in the system. Section 4 describes banking system dynamics over time. The last section concludes.
2 Literature review

The section discusses the most recent studies (2010-2017) that define the conditions to ensure the financial stability of the banking system. Most papers apply the agent-based modelling approach. The subsections 2.1 and 2.2 focus on the impact of the interbank lending market structure and regulatory restrictions on financial stability. The subsection 2.3 summarizes other measures to prevent system fragility.

Macroeconomic models of the last generation, developed by the European project CRISIS or Sorbonne and Bielefeld universities, simulate the processes of bank lending to the real sector and assess their impact on economic indicators. In these studies, the interactions between firms and banks are represented as a matrix "input-output" or the bipartite graph "company-banks". The graph is recognized systemically crucial by [Stiglitz et al., 2009]. [Iori et al., 2006] studies the network structure formations changing the external parameters.

The Russian banking system is less often designed by agent-based models than developed economies. Among the recent works [Ponomarenko and Sinyakov, 2017] show the impact of the strengthening banking supervision on Russian banking system. The results obtained by the agent-based model are the following. In the short run period, small and medium-sized banks weaken, but the credibility of such banks will begin to grow as a result of the banking system recovery that creates a positive long-term effect. In the long-term period, average and small banks increase deposit base and strengthen the capital adequacy compared with the state where recovery is not happening.

2.1 The effect of the interbank network structure on financial stability

There is a large literature on network risks in the banking system since 2009 when there was a need to study systemic risks caused by mutual obligations. The pioneering work [Alessandri et al., 2009] investigates a cascading default, when the bankruptcy of one bank may lead to the bankruptcy of their counterparties and so on. It is particularly important that such risks can only be mitigated by regulators. The systemic risks designed by graphs were described by [Acemoglu et al., 2013] and [Gleeson et al., 2012]. The literature mainly considers the cascading default, while the same risks associated with liquidity have received far less attention.

The systemic risk has decreased in the world banking network from 2011 to 2014 compared to 2009 due to the change in the asset distribution (overnight, short-term and long-term loan, etc.) [Liu et al., 2017]. Moreover, the early studies focus on an exogenously formed interbank market (not including scoring of counterparties) that overestimates losses during the crisis [Liu et al., 2017].

Financial stability within network structure is much more complicated. First, some interbank markets (e.g. Germany) are characterized by significant clustering [Wolski and van de Leur, 2016]. Therefore, a credit portfolio of the small bank remains unaffected after money supply reduction. Regulators have to adopt a more aggressive monetary policy, which affects macroeconomic performance adversely. Secondly, the increasing network complexity (the

\footnote{The number of Russian banks reduced from 1136 to 567 from 01.01.2008 to 01.12.2017.}
growth of payment systems transactions) reduces the financial stability significantly because of the risk of late payments. The Bank of England partially solved the second problem and [De Caux et al., 2016] modified the solution. In the results, any non-priority payments, which are inside the bank queue (because of liquidity is less than buffer) should be initially included in the liquidity-saving mechanism (LSM). However, once liquid funds exceed its buffer, the payment should be removed from LSM and settled through real-time gross settlement (RTGS).\(^3\) Also, the Bank of England has introduced a minimum share of banks daily flow, which must be resolved by a certain time. In the US, 50% of the daily flow should pass to 12 AM; 75% by 2.30 PM.

A network structure determines the probability of bail-out [De Caux et al., 2017]. The author estimated the optimal bail-out probability for three network types: 63%, 67%, and 75% for lattices, 2-dimensional small-worlds, and scale-free networks of average degree equals 8, respectively.

### 2.2 Capital requirement - too high or too low?

There is an ambiguous conclusion about what must be the bank regulatory requirements (if indeed they should be). The papers note that the introduced prudential regulation is (a) adequate and do not require changes [Rubio and Carrasco-Gallego, 2014]; inadequate and (b) should be increased [Dewatripont et al., 1994]; [Admati et al., 2013]; [Blinder, 2013]; [Miles et al., 2013]; [Chang, 2014]; [Kindleberger and O’Keefe, 2001]; [Clerc et al., 2014]; [Davis et al., 2016]; [Chan-Lau, 2017]; or, on the contrary, (c) require reducing - [Selgin, 1996]; [Repullo, 2004]; [Gorton, 2012]; [Nguyen, 2014]. Another group opt for dynamically adjusted regulation, e.g. dynamic provisioning [Fernández de Lis and García-Herrero, 2010] and dynamic capital adequacy ratio.

The last actual Basel III standards does not mitigate the systemic risks compared with the Basel II. [Popoyan et al., 2017] have shown that the banks’ default rate is lower for Basel II and reaches its maximum with Basel III LCR regulation. The marginal effect of add-on to Basel III capital requirements on financial stability is negative.

As in the previous work, [Shaw et al., 2013] and [Aikman et al., 2015] prove the nonlinear relationship between capital requirements and the consumption. While [Shaw et al., 2013] observed an inverted U-shaped relationship between these parameters, [Aikman et al., 2015] proved only the increasing part of this curve (capital adequacy ratio, CAR, is 15% on the peak consumption), then the value of the optimum is down to 0. In other words, if the macroeconomy continues to improve significantly, there comes a time when capital requirements cannot resist risky behaviour. Then the optimal level will be zero capital requirements. That is, the local maximum falls below the level of welfare achieved a zero capital requirement.

[Catalán and Ganapolsky, 2014], [Malherbe, 2015], and [Karmakar, 2016] propose to introduce dynamic (countercyclical) regulations. The constant capital requirements through the cycle lead to irretrievable losses of banks. [Malherbe, 2015] reports the optimum of capital requirements as an explicit function of the recent financial shock and all past productivity shocks. According to [Karmakar, 2016], the transition from a fixed capital requirements of 8% will lead

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\(^3\)RTGS payment will be made if a bank will have enough money; otherwise, the order will be rejected. LSM payment will be postponed to until the payer does not replenish the account.
to a quarterly increase of permanent consumption in an average country from 0.094% to 0.651% for a moderate counter-cyclical regulation and 0.281% to 0.778% for aggressive countercyclical regulation. [Occhino, 2017] estimated that capital requirements should be increased by 0.28 percentage points in response to the bank loan supply extension by 1%, and by 0.32 percentage point in response to a 1% increase in the expected credit spread on bonds issued by banks. Also, capital requirements should be reduced by 0.95 percentage points in response to a bank’s losses in an amount equivalent to 1% of total bank assets.

The option is to change accounting methodology. So, if the capital requirement remains unchanged, but more conservative requirements for reserves (IFRS 9) is introduced, the level of financial system stability will not change [Agéñor and da Silva, 2017]. In other words, IFRS 9 and capital regulation are rather complementing than substituting. Both policies are designed to have a positive effect on financial stability, but the effect is not higher with the joint introduction of the two modes at the same time. Thus, without IFRS 9 the capital regulation does not deteriorate financial stability.

[Shaw et al., 2013] and [Rubio and Carrasco-Gallego, 2016] note that hard capital requirements weaken the effectiveness of monetary policy. [Rubio and Carrasco-Gallego, 2016] showed that increasing capital requirements increase the sensitivity of inflation and output to the interest rate. For example, under Basel I and II (capital adequacy ratio (CAR) = 8%) the sensitivity of inflation and output is 17.6 and 5.8, respectively. Under Basel III (CAR = 10.5%) the sensitivity of inflation and output increases to 20.7 and 6.6. So Basel III requires a more aggressive monetary policy, which could shock the economy. As a result, it leads to the opposite effect (macroeconomy deteriorates). So [Shaw et al., 2013], [Rubio and Carrasco-Gallego, 2016], [Primus, 2017] and [Popoyan et al., 2017] propose to increase financial stability and reduce fluctuations of GDP simultaneously with Basel III by the Taylor rule (minimize the inflation and output variance and variance of borrowing).

2.3 How to improve financial stability?

In addition to the capital requirements adjustments and the Taylor rule, the researchers proposed to (1) combine regulation and supervision [Buck and Schliephake, 2013]; (2) depart from international harmonization of the regulatory requirements [Buck and Schliephake, 2013], [Ermolova and Penikas, 2017]; (3) increase the certainty of a regulator’s intervention; (4) reduce dividends [Ricetti et al., 2016]; (5) move from regulation under Basel II and Basel III to the tax on systemic risk [Poledna et al., 2017]; (6) does not limit a bank lending policy [Ashraf et al., 2017]. Next, each of the proposal will be commented.

The first initiative helps to reduce the collapse likelihood while regulation reduces only the amount of loss in recession [Buck and Schliephake, 2013].

The second initiative concludes that uniform capital regulation increases the total cost of the intervention [Buck and Schliephake, 2013], and the homogeneity of risk regulation leads to its more rapid response to the crisis [Ermolova and Penikas, 2017]. Therefore, regulation needs to be more heterogeneous than homogeneous.

The third initiative of [Clark and Jokung, 2015] notes that the increased uncertainty resulting from the regulation (for example, incidental costs or imperfect timing of regulatory
intervention) affects both the stability and performance of the financial system. It follows that the regulator needs to reduce the uncertainty of their policy.

The fourth initiative [Riccetti et al., 2016] based on the finding about negative nonlinear dividend effect on the macroeconomy and financial stability. Dividend payment reduces a company net worth. Firms need more loans, while banks reduce their offer. It implies the system’s volatility. It exacerbates the problem of insufficient demand, and could lead to a prolonged recession.

The fifth initiative is concluded based on the comparison of losses in three regimes: Basel II, Basel III and the tax on systemic risk. A tax on systemic risk is proportional to the contribution of a bank to systemic risk level [Poledna et al., 2017]. The tax on systemic risk is more effective than G-SIBS surcharges. The latter one changes the loss distribution slightly. We need to note that concept is too abstract as centrality measures are associated with systemic risk, but latter is unobservable; hence unmeasurable and non-verifiable.

The sixth initiative is derived from the agent-based model [Ashraf et al., 2017] that incorporates four agents (household, firms, banks, and regulator) over 60 years. The number of firms in the system is endogenously determined, and their decisions are based on whether a bank will lend them. Banks select the firms relative to loan-to-value (LTV). As a result, banks bring more benefit (not funded by ”bad” firms) than costs (the loss due to collateral) for macroeconomy. However, the market (a self-regulating economy) will not recover being far from a steady state if it is not backed by a policy of stabilization.

To sum up, the volume of transactions that depend on the internal permissions (limits) plays an important role in the spread of shocks in the interbank market. The system of limits is set up so that there are intermediary banks, which increasingly receive funds from other banks (including the Central Bank) and give them to other banks than lend to companies. Cascading the closure limits during the crisis exacerbates the stress state of the economy, as it does not allow to read potentially implemented counter-claims and obligations. However, the system limits and the presence of intermediary banks has not been investigated in the literature.

3 Model description

This is the initial setting to be further enhanced. The model under consideration describes a banking system functioning in the following three markets, see Fig. 1:

- Credit market, in which banks lend to their clients (non-banks, non-financial institutions (non-FI); those clients are corporate (legal entities) and retail (natural person);
- Deposit market, in which banks take deposits from non-FI;
- Interbank market, in which banks lend to each other, i.e. to FIs.

The systems evolve in discrete time with an elementary time step equal to one day. A year includes 12 months having 20 working days each. At the initial moment \( t = 0 \) we specify initial conditions and then let the system run. Those parameters are important to replicate real-world
banking where bankruptcies occur because of daily and intraday payment delays (e.g. Herstatt bank default case in 1974 or Lehman Brothers in 2008), though at yearly horizons banks were solvent and could have met all obligations.

3.1 Credit and deposit markets

Deposits and loans are generically characterized by the time of arrival (creation), volume, maturity, rate and structure of interest payments. Some notations for these characteristics are given below in Table 1. Currently we assume mono currency banking system, though afterwards it is to be incorporated as another model parameter for loans and deposits.

Table 1: Notations for characteristics of deposits and credits

<table>
<thead>
<tr>
<th>Model parameter</th>
<th>Market</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Credit</td>
</tr>
<tr>
<td>Volume</td>
<td>$V_c$</td>
</tr>
<tr>
<td>Rate</td>
<td>$r_c$</td>
</tr>
<tr>
<td>Maturity</td>
<td>$M_c$</td>
</tr>
<tr>
<td>Mean number per day</td>
<td>$N_c$</td>
</tr>
<tr>
<td>Interest payment</td>
<td>$\Omega_c = r_c \times N_c$</td>
</tr>
</tbody>
</table>

In this paper, we consider a simple model of loan and deposit markets with externally generated supply (deposit offers) and demand (loan) realized as stochastic processes. The corresponding sequence of operations starts with accepting a deposit (offering a loan), paying out (collecting) interest at some specified frequency and ends up with paying back (receiving) the principal of a contract. The economic "engine" of the model is the spread (margin) $r_c - r_d$ between the credit and deposit rates serving as a source for banks profit.
3.2 Operational protocol

3.2.1 Real and model daily operational protocol

The operational banking protocol employed in Russia includes the following main stages:

- Interbank transfers are realized five times a day (five trips, runs) from 9 AM till 9 PM. The overnight interbank operations proceed through lending money at 9 PM and receiving them including interest payment back at 9 AM on the next day.
- Operations for private clients are performed from 9 AM till 3 PM (until the third trip).
- Operations with organizations are performed from 9 AM till 6 PM (until the fourth trip).
- The fifth trip is used for interbank operations only.

In the simplified model used in this paper the daily operational protocol includes the following main stages to replicate banking daily payments processing:

1. Arrival of requests for accepting deposits and providing loans. Calculation (but not yet payment) of interest. A random distribution of requests among the banks. The deposits are assumed to be always accepted, the provision of loans is not automatic and is a result of a consideration specified by a protocol.
2. Repayment of loans.
3. Calculation of the resulting balance and formation of interbank deals taking into account applications for loans and the necessity of paying interest. It is assumed that loans on the interbank market and the corresponding interest payment are returned at the next stage.
4. Netting of the offered and taken interbank loans. The matching is made at random, and a large request can be distributed among several banks.
5. The unsatisfied requests are eliminated, the interbank loans, the corresponding interbank interest as well as external (that on deposits) interests are repaid.
6. External (not interbank) loans are approved and offered provided the banks have enough resources.
7. Day’s closure. Check out for bankruptcy (impossibility of meeting obligations) and implementation of the bankruptcy protocol in the case the obligation cannot be met.

At the end of each day it is decided whether on the next day there appears a new bank. A decision is made by comparing $p_{\text{BankCreation}}$ calculated as

$$p_{\text{BankCreation}} = a_0 + a_1 \left( \frac{2}{\text{AssetIndex}} \right) \left( \frac{\text{TA[AssetIndex]} - \text{TA[0]}}{\text{TA[AssetIndex]} + \text{TA[0]}} \right) + a_2 \left( \frac{N_{\text{Bankruptcy}}}{\text{AssetIndex} \times N_{\text{Bank}}} \right)$$

(1)
where TA is the total assets, \(N_{Bankruptcy}\) is the number of bankrupt banks, \(N_{Bank}\) is the total number of banks, the values of the parameters \(a_{0,1,2}\) were chosen as \(a_0 = 0\), \(a_1 = 0.5\), \(a_2 = 10\), with a random number \(p_{rand}\) in the interval \([0,1]\). If \(p_{BankCreation} > p_{rand}\), a new bank is created.

The initial capital of the newly created bank is determined using its current distribution in the Russian banking system (see Figure 2).\(^4\)

### 3.2.2 Bankruptcy protocol

A bank that does not meet its obligations at the end of the day is considered bankrupt. Technically this means that

- The bank is no longer accepting deposits and stops participating in the interbank market.
- The remaining capital is proportionally distributed among its creditors if the assets are non-negative or not less than the capital in absolute terms.
- The remaining obligations for all creditors are recorded, and deposits are closed.
- Hand out of the remaining obligations concerning other banks to Deposit Insurance Agency (hereafter - DIA). Not all obligations can be met.
- Delist the bank from the list of active banks.

### 4 Evolution of the banking system

The key twofold functionality of the banking system is to take deposits and pay interest on them and, using deposits as a source, provide loans and collect interests from them. The entry flow of deposits provides a source for loans and, in turn, loan interest provides a source of paying interest on deposits. Therefore, the banking system is balanced or growing if interest on loans \(\Omega_c\) does on average exceed or, in the worst case, is equal to the interest on deposits \(\Omega_d\) that the banks have to pay. The precise description of the structure of \(\Omega_c\) and \(\Omega_d\) depends, in particular, on the characteristics of deposits and loans listed in Table 1, e.g. on currency and maturity.

Intuitively one expects three characteristic regimes of the dynamical evolution of the model banking system under consideration. As for now, we assume no credit risk on the non-FI client side, i.e. all loans offered are paid pack. Indeed, for \(\Omega_c > \Omega_d\) the banking systems expands by accumulating capital, for \(\Omega_c < \Omega_d\) it shrinks and, eventually, disappears and for \(\Omega_c = \Omega_d\) the system characteristics fluctuate around some constant level. This intuition is confirmed by the analysis of simulation results presented below.

In what follows we shall restrict our consideration to the case of fixed deposit and credit volumes \(V_d = V_c = 100\) and equal or close maturity \(M_d\) and \(M_c\). So one can expect that the

\(^4\)It is assumed that a bank can start working on the market only if the bank has capital above some specified minimal threshold (for now - more than 0).
characteristic features of the evolution of banking system will mainly depend on the spreads $N_c - N_d$ and $r_c - r_d$ determining the interrelation between the volumes of credit demand and deposit supply and the corresponding rates.

In our simulations we considered two sizes of the banking system ($N_B = 10$ and 600 banks, respectively); two types of initial capital distribution (uniform and realistic initial bank capital distribution). The latter is shown in Fig. 2 for the case $N_B = 600$.

![Real initial distribution of capital](#)  

**Figure 2**: Histogram of the initial distribution in bank capital, $N_B = 600$.

In agreement with the above-described intuitive arguments (stylized facts), the results of our simulations can indeed broadly be described as showing three characteristic regimes:

- **Regime I.** The regime characterized by the growth of capital in the banking system, observed when $\Omega_c > \Omega_d$, e.g. in case when $r_c > r_d$ and $N_c/N_d < 1 + \delta$, where $\delta$ is a small positive number.

- **Regime II.** The regime characterized by the fluctuating capital in the banking system, observed when $\Omega_c = \Omega_d$, which holds, for example, when $r_c = r_d$ and $N_c = N_d$.

- **Regime III.** The "Ponzi" regime is characterized by the decline of capital in the banking system observed when $\Omega_c < \Omega_d$, e.g. when $N_d$ is significantly smaller than $N_c$ or the spread $r_c - r_d$ is negative.

4.1 Small banking system

Let us first discuss the simulation results for the small banking system with $N_B = 10$. In this paragraph we will analyse only the case of uniform initial capital distribution, as the number of banks in the system is too small to represent the realistic distribution correctly.

Let us consider the case when the average number of deposits and loans per day is balanced, i.e. $N_d = N_c$. Then, as expected, the positive spread $r_c - r_d > 0$ ensures the regime of capital
growth, the negative one \((r_c - r_d < 0)\) - the declining capital regime and the regime with fluctuating capital is observed when \(r_d = r_c\). Figs. 3 and 4 present evolution of capital and assets in the system.

We see that the evolution of the model banking system, shown in Figs. 3(a) and 4(a), is characterized by the steady growth of the overall capital and assets. In Figs. 3(b) and 4(b) we see the regime of fluctuating capital and Figs. 3(c) and 4(c) represent the regime of capital decline. The last two regimes are both characterized by significant fluctuations of capital and assets. However, in declining capital regime the capital becomes negative at \(M = 301\) and does not return to the positive semiplane. In contrast, the fluctuating capital regime is mostly characterized by positive total capital.

\[
\begin{array}{c}
\text{(a) Regime I. } r_c = 15\%, \ r_d = 10\% \\
\text{(b) Regime II. } r_c = 10\%, \ r_d = 10\% \\
\text{(c) Regime III. } r_c = 10\%, \ r_d = 15\%
\end{array}
\]

Figure 3: Evolution of capital in the three regimes in case of uniform initial capital in the small banking system. \(N_B = 10, \ M_c = M_d = 200, \ N_c = N_d = 10\), total initial capital is equal to 1000
Regime I. $r_c = 15\%, r_d = 10\%$

Regime II. $r_c = 10\%, r_d = 10\%$

Regime III. $r_c = 10\%, r_d = 15\%$

Figure 4: Evolution of assets in the three regimes in case of uniform initial capital in the small banking system. $N_B = 10$, $M_c = M_d = 200$, $N_c = N_d = 10$, total initial capital is equal to 1000

Let us note that the three regimes in general are determined by the relationship between $\Omega_c$ and $\Omega_d$. Therefore, one can consider a setup in which we expect the regime of capital decline for the same value of positive interest spread as in the example at Figs. 3(a) and 4(a). This can be insured by the dramatically insufficient demand for credit. In Fig. 5 we display the results of simulations with $N_c = 1$ in contrast to the previous case of $N_c = 10$.

4.2 Large banking system

Let us now discuss the simulation results for the large banking system with $N_B = 600$. In this paragraph we will consider two types of the initial capital distribution: uniform distribution (equal initial capital in all banks) and the realistic one. The total starting capital in the banking system was approximately the same in both cases.

The evolution of total capital and total assets in the banking system in the three regimes described above is shown in Fig. 6 and 7 respectively. The results are qualitatively similar to
Figure 5: Evolution of capital and assets in the regime of capital decline when the interest rate spread is positive. $N_B = 10$, $M_c = M_d = 200$, $N_c = 1$, $N_d = 10$, $r_d = 10\%$, $r_c = 15\%$, total initial capital is equal to 1000 those for $N_B = 10$.

Figure 6: Evolution of capital in the three regimes in case of uniform and realistic initial capital distributions. $N_B = 600$, $M_c = M_d = 200$, $N_c = N_d = 1000$, total initial capital is approximately equal to $39 \cdot 10^5$. 

(a) Regime I. $r_c = 15\%$, $r_d = 10\%$

(b) Regime II. $r_c = 10\%$, $r_d = 10\%$

(c) Regime III. $r_c = 10\%$, $r_d = 15\%$
Figure 7: Evolution of assets in the three regimes in case of uniform and realistic initial capital distributions. \( N_B = 600, M_c = M_d = 200, N_c = N_d = 1000, \) total initial capital is approximately equal to \( 39 \cdot 10^5 \)

4.3 Interbank market

Of special interest is, of course, the properties of the interbank market. We expect that the corresponding activity increases at times of cash shortage. Evolution of the interbank market size to capital ratio is shown in Fig. 8. In particular, the interbank market shrinks when system is in the growing capital regime (Regime I) and increases in time in case of declining capital regime (Regime III). Regime II is characterized by fluctuations of the ratio of interbank market size to total capital ratio. For realistic initial capital the above hypothesis is confirmed by the simulation results shown in Fig. 9. However for the uniform initial capital case the dependence between cash and interbank market activity is not the same.
Figure 8: Evolution of the interbank market size to capital ratio in the three regimes in case of uniform and realistic initial capital distributions. $N_B = 600$, $M_c = M_d = 200$, $N_c = N_d = 1000$, total initial capital is approximately equal to $39 \cdot 10^5$.
Figure 9: Relationship between interbank market size and liquidity in the three regimes in case of uniform and realistic initial capital distributions. $N_B = 600$, $M_c = M_d = 200$, $N_c = N_d = 1000$, total initial capital is approximately equal to $39 \cdot 10^5$
5 Conclusion

The paper will be further developed as follows. The system, where new banks are not created, will be considered separately. The paper will study and describe the network of interbank market in more detail.

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