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Agent-based modelling of macroeconomic shocks in a banking sector

Introduction and overview of underlying theory

Along with the great financial crisis, the perceived importance of banking sector and its influence on the real sphere of the economy has sharply rose. At the same time the academics directed its focus on researching the economic mechanics of the underlying sector, especially, its reaction to economic disturbance, which infamous example is the GFC. Before the crisis, the models made by the economists, as it has been realized as well, has not incorporated the financial sector enough, which is one of the reasons, that economic scene has failed tremendously, by not forecasting the global economic downturn or at least identifying the stage of the business cycle.

Herein article is divided into few parts. First one briefly presents the related theory of the agent based modeling, along with the most popular alternative in a current applied macroeconomic research. Next, model description chapter will be devoted to present agents that are included in the model. It is thus divided into three parts, each describing a behavior of particular agent. Another chapter shows the process and actual parameters applied during deployment of a simulation. The following part attempts to make a reasonable inference from the model regarding the banking sector and chosen shocks. The last one is conclusion. The goal of this research is to propose a theoretically robust model for analyzing shocks experienced by banking sector and gather insights from it for policy-makers.

Banking sector as well as many other elements of economy is a complex system, which is built upon many interactions between its participants, each of which is heterogenous in its actions. This is one of the main struggles that face the researchers while striving to explain the mechanics and to perform accurate forecasts. The main work-horse of the academics, that are aiming to understand the foundations of economy, for quite a time are equation-based models, called dynamic stochastic general equilibrium (henceforth, DSGE). Their assumptions are not including heterogeneity of agents, as well as making other potential misconceptions. Which is to say, the unlimited rationality, homogeneity and in terms of modelling the business cycle, the fundamentally incorporated propensity of the economy to return toward the equilibrium. The popularity of these, notably among central banks, is mainly due to its robust microeconomic foundation thanks to which, their inferences are not suffering from the Lucas critique, i.e. the behavioral parameters ruling the model are "policy-invariant". Notwithstanding all of that, their exceptional acceptance was acclaimed by the introduction of Bayesian estimation of DSGE models in a seminal work of Smets and Wouters (2003, 2007)[1] when their forecasting ability was also comparable to typically econometric methods such as vector autoregression.

However widely, the DSGE framework is used, it has proven to be of limited value in analyzing the markets system, at least in the light of the great financial crisis. It is not yet by those who consider themselves as heterodox economists but to wide spectrum of representatives of economic schools of thought, including some notable noble prize winners (e.g. P. Krugman[2], J. E. Stiglitz[3], P. Romer[4] and J. Galí[5]). With that being said, it appears that one of the most important reasons for these models to maintain status quo in the modelling framework is the lack of alternative. Albeit, there indeed has emerged a valuable approach to modelling economy, which is fundamentally different from new neoclassical synthesis. The proposed paradigm is called agent-based modelling (hereinafter referred to as ABM). It's a computer simulation of agents with a given set of heuristics, that attempts to reflects, in a general way, the actual behavior of their underlying real-world equivalents[6]. Ergo, they represent a person or an entity that is an essential participant of the analyzing system. Usually, those heuristics are constructed in accordance to a particular stylized fact from an economic literature, e.g. banks tend to pay dividends, when their capital adequacy is sufficient[7]. A key feature is the heterogeneity of these agents. Each of them might be assigned with a unique characteristic that differentiate it from other agents in a model, therefore, in opposite to the DSGE models, there is no 'representative agent'. The ABM relax other core assumptions to the New Neoclassical Synthesis,

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[1] F. Smets, R. Wouters, *Forecasting with a Bayesian DSGE model: an application to the euro area*, "JCMS: Journal of Common Market Studies" 2004, vol. 42 (4), p. 841–867; F. Smets, R. Wouters, *Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach*, "American Economic Review" 2007, vol. 97, no. 3, p. 586–606.

[2] P. Krugman, *The State of Macro Is Sad (Wonkish)*, "The New York Times", 12.08.2016, Blog P. Krugmana w ramach portalu New York Times, krugman.blogs.nytimes.com/2016/08/12/the-state-of-macro-is-sad-wonkish/ [access: 05.04.2020].

[3] J.E. Stiglitz, *Where Modern Macroeconomics Went Wrong*, NBER Working Paper no. 23795, 2017, p. 6–16.

[4] P. Romer, *The Trouble with Macroeconomics*, Delivered January 5, 2016 as the Commons Memorial Lecture of the Omicron Delta Epsilon Society, p. 5.

[5] J. Galí, *Some scattered thoughts on DSGE models* [in:] *DSGE Models in the Conduct of Policy: Use as intended*, CEPR Press, London 2017, p. 86–92.

[6] L. Hamill, N. Gilbert, *Agent-Based Modelling in Economic*s, Wiley, Hoboken 2015, p. 4.

[7] R.N. Dickens et. al., *Bank Dividend Policy: Explanatory Factors*, "Quarterly Journal of Business and Economics" 2002, vol. 41, no. 1/2, p. 9.

particularly the rationality or model-consistent expectations of the agents[8]. In ABM, the rationality is replaced with bounded rationality, namely the decision of each agent is based on the partial information asymmetry and with limited computational capability. Still, ABM models share some characteristics with beforementioned equation-based models. The main one is the approach of modelling macroeconomic phenomena from a microeconomic activities. Due to this method, the ABM have a valuable property of emergence, which is appearance of complex systems with novel properties from simple interactions.

1. Model description

The model described in herein work is rather a simple depiction of a banking sector. Yet, includes most of the core aspects of modern banking sector, thus it might be as well used as a general framework and a basis for further extension of choice. The model is loosely inspired on the following papers: IMF work by Jorge A. Chan-Lau[9], S. Poledna et. al[10] and B. LeBaron[11]. It is also appropriately modified in order to fit the phenomena analyzed in this paper. The script of the simulation is entirely written in R programming language, without the use of libraries made strictly for ABM. In order to contribute or simply use the model, one may find the whole script on the author's github[12], which host it in a single file. Variables of simulation are approximately deducted from Polish economic statistics, however without some further extensions, the inference from this model cannot be extrapolated exclusively on the polish economy.

There are 3 types of agents included in the model. Households, which provides funds via deposits and may revoke them likewise. Firms, that are borrowing money for their uncertain investment projects. Third, and the most complex one, given the set of rules, are banks. These are intermediaries between household and firms. That being said, they lend loans to firms with the funds taken in the form of deposits from household, whilst managing the widely understood risk. Techni-

8 J. Farmer, D. Foley, *The economy needs agent-based modelling*, "Nature" 2009, vol. 460, p. 685.

9 J. A. Chan-Lau, *ABBA: An Agent-Based Model of the Banking System*, IMF Working Paper 2017, WP/17/136, p. 8–15.

10 S. Poledna, M. G. Miesse, C. Hommes, *Economic Forecasting with an Agent-based Model*, Available at web library SSRN: https://ssrn.com/abstract=3484768, 2019 [access: 05.04.2020], p. 4–6.

11 B. LeBaron, *A Real Minsky Moment in an Artificial Stock Market*, Business School, Brandeis University Working Paper, 2012, p. 3.

12 *Website for software development version control in Git*, https://github.com/SquintRook [access: 05.04.2020].

cally speaking, the lack of some of the agent's characteristics makes them not complete 'agents' by the criteria proposed by North and Macal[13]. These are the following: heterogeneity, capability to modify their actions, responsiveness, and autonomy. Amongst aforementioned agents, banks are complete agents according to these criteria, households are not autonomous and firms are not exhibiting autonomy nor, adaptive behavior. The simulation consists of periods, during each one every agent is performing their tasks and reacting to other agent's actions.

1.1. Households heuristics

At the initial phase of the simulation, each household is assigned to one of the available banks with a random probability from the uniform distribution. Every deposit is of unit value which does not change along with the simulation. Further periods of simulation start with interest payment from the banks to deposit holders. Households have no negotiating power over banks, therefore they get interest that is imposed by the bank. Households don't reinvest earned interest but consume it immediately. Later on, households change their bank of choice with given probability.

The probability to change the bank by the household is exogenously assigned to every household randomly, from the uniform distribution $U(p_{h,min},p_{h,max})$. There is only single exception, during which the given probabilities may change. Particularly, when the bank, which holds the deposit of the given household, have generated negative income during preceding period. In this case, the initial probability is increased by the exogenously stated value. This rule is not intended to incorporate the bank run phenomena, but to merely grasp how deposit holders react to uncertainty about the future of the bank.

1.2. Borrowers heuristics

Borrowers are using funds of households through banks to invest them in risky undertakings. Each borrower has three heterogenous attributes that are provided into the model at the beginning of the simulation. Probability of default of the borrower p_b during every period of the simulation, loan value $l_{b,t}$ and the bank from which the loan is taken. The probability of default is randomly given from the uniform distribution $U(p_{h,min},p_{h,max})$. Other attributes are risk weight in the bank loan portfolio and cost of capital imposed by the bank. All of them are calculated en-

[13] M. North, C.M. Macal, *Managing Business Complexity: Discovering Strategic Solutions with Agent-Based Modeling and Simulation*, Oxford University Press, Oxford 2007, p. 27.

dogenously and might be a subject to change depending on other factors. The formula for banks to quote cost of capital is:

1

$$r_b = \left(\frac{\left(1 + (1 + m_b) \times r_{free}\right) - p_{b,t} \times rr}{1 - p_{b,t}} \right)$$

Where, rr is recovery rate, that is constant throughout the simulation for every loan. m_b is a margin imposed by the bank on the loan. r_{free} is the risk-free rate of return and $p_{b,t}$ is probability of default of the given borrower in the period t. The potential risk weight of a borrower in a loan portfolio of bank is a linear function:

2

$$rw_{b,t} = f\left(p_{b,t}\right) = 0.5 + 5p_{b,t}$$

1.3. Bank heuristics

Banks are primary agents of the model and are also subject to inference in the later part of the paper. They have several attributes that can be divided into: state of financial situation, simple balance sheet and P&L statement. Balance sheet is the most essential to the operational decisions made by a bank. On the liabilities side it consists of initial equity, that every bank has the same at the beginning, sum of deposits and reserves at the central bank. Equity might be obviously increased after generated income by the bank. Sum of deposits fluctuate rather independently from the bank perspective but can be revoked by the bank if it decides to decrease its operational activity. Reserves $RES_{bank,t}$ at the central bank is calculated as:

Reservas = (Somatório conj. emprestimos* tx de juros paga pelo empréstimo) - (Somatorio dos depositos * tx de juros dos depositos) - Variação da prov. das perdas esperadas

3

$$RES_{bank,t} = \sum_{l \in L_{bank,t}} l_{b,t} - \sum_{d \in D_{bank,t}} d_{h,t} + E_{bank,t} + EL_{bank,t}$$

Also the bank must fulfill the minimal reserves ratio:

4

$$RES_{bank,t} > MRR_t \times \sum_{d \in D_{bank,t}} d_{h,t} \qquad = (2)$$

Where, $L_{bank,t}$ is the set of solvent loans in a loan portfolio of a bank in period t, $l_{b,t}$ value of the particular loan of the borrower, $D_{bank,t}$ set of the deposits in a given bank, $d_{h,t}$ deposit value of the household, $E_{bank,t}$ is equity, which also must be in accordance to the capital adequacy ratio CAR_t:

5

$$E_{bank,t} > CAR_t \times \left(\sum_{l \in L_{b,t}} l_{b,t} \times rw_{b,t} \right) \qquad = (1)$$

$EL_{bank,t}$ are expected losses reserves of the bank, calculated as

6

$$EL_{bank,t} = \sum_{l \in L_{bank,t}} l_{b,t} \times p_{b,t} \times rr \rightarrow 1 - rr$$

MRR_t is given exogenously and might be a subject of shocks. If a bank's reserves are under minimal required reserves, then it is forced to sell its loan at the significant discount to raise liquidity. Sold loans are not bought by other banks in the model.
P&L statement is built from revenue $REV_{bank,t}$, cost $C_{bank,t}$ and income $I_{bank,t}$ Revenue mostly comes from loan interest and is calculated as follows:

7
$$REV_{bank,t} = \sum_{l \in L_{bank.t}} l_{b,t} \times r_{b,t-1} + RES_{bank,t-1} \times r_{free,t-1}$$

Cost may change depending on the sudden liquidity need of the bank but generally is calculated as:

8
$$C_{bank,t} = \sum_{d \in D_{bank,t}} d_{h,t} \times \left[r_{free,t} \times (1 + m_h)\right]$$

Where m_h is the exogenously stated risk premium for households to discount for the bank deposits being riskier than holding cash or treasury bonds. There is a fundamental difference in risk level of deposits and loans, ergo the inequality $m_h > m_b$ must be satisfied. Income $F_{bank,t}$ is simply the difference between $REV_{bank,t}$, and $C_{bank,t}$. It is added to the equity at the end of the period.

For another group of bank attributes, dummy encoding was used to indicate their state of financial condition. These are dichotomous variables $\in \{0,1\}$, where:

9
$$state = \begin{cases} 0, & if\ a\ bank\ is\ not\ in\ a\ given\ state \\ 1, & if\ a\ bank\ is\ in\ a\ given\ state \end{cases}$$

First state is the bankruptcy, it occurs when $E_{bank,t} \leq 0$. In that case, the bank revoke deposits, sell its loans and allow other banks to acquire its clients. After the bankruptcy, the bank is no longer taken into considerations of a further simulation. Financial condition, that is less problematic for bank is undercapitalization. Banks are undercapitalized when they don't meet capital adequacy requirement described on previous page. To raise liquidity, banks receive liquidity assistance from central bank and must pay interest with a margin over risk free rate.

2. Simulation procedure

The simulation procedure can be broadly described as a for-loop, with one exception being the $t = 1$ period, which is the initial one, therefore it differs from those later on. Every period has the same order of actions and calculations involved. Exogenous variables of each agents are calculated as described before and are eventually, changed during the simulation. The initial period starts with building loan portfolio by the banks. During this action they calculate the maximal funds to lent, given minimal reserves and capital adequacy requirements, which is:

10
$$min\left[\left((1-MRR_t)\times\sum_{d\in D_{bank,t}} d_{h,t}\right),\left(\sum_{l\in L_{bank.t}}^{n=n_a} l_{b,t}\right)\right]$$

Where:

10.1
$$n_a=\left|\left\{a_i\in(A)_i^{|L_{bank.t}|}\,\middle|\,a_i<E_{bank,t}\right\}\right|$$

10.2
$$(A)_i^{|L_{bank.t}|}=a_{i-1}+l_{b,t}\times rw_{b,t}\times CAR_t$$

In other words, for capital adequacy ratio, banks are summing first n_a loan values, where n_a is equal to the number of elements from subset of a sequence $(A)_i^{|L_{b,t}|}$, that satisfy inequality $a_i < E_{bank,t}$. Given the fact that there might be many combinations of loan portfolios, more or less efficient, one may conjecture that described solution is suboptimal to utilizing techniques from mathematical optimization. However, the author opts to choose this way, for it is less computationally expensive.

Every period of simulation starts with households withdrawing their deposits and allocating them in different banks, with lower probability to those who suffer loss during previous period. Next, loans default with exogenous probability and later on are worth zero. Along with principal of a loan, the bank loses interest due as well. At the same time, the banks are calculating losses from defaults, which is consequently:

11
$$\left(\Delta\sum_{l\in L_{bank.t}} l_{b,t}\times r_{b,t-1}\right)\times(1-rr)$$

After changing deposits and loan defaults, every bank check whether it meets reserve requirements. Those who lack necessary liquidity are selling their loans as described in the previous part of the paper. Next, banks are calculating their preliminary P&L statement to update their equity and check in which of the predefined financial conditions they are. If their equity is over capital adequacy target, then banks choose to pay dividend, which is equal to the excess amount of capital over target capital adequacy. Those banks who have enough liquidity are increasing their lending activity with similar approach as described on the previous page. Available funds for loans are calculated as follows:

$$min\left[\left\{AF_{banks,t}\in\{ER_{bank,t},EC_{banks,t}\}\,\middle|\,AF_{banks,t}>0\right\}\right]$$

12

$$ER_{bank,t} = RES_{bank,t} - MRR_t \times \sum_{d \in D_{bank,t}} d_{h,t} \tag{13}$$

$$EC_{banks,t} = \sum_{l \in L_{bank.t}}^{n = n_a} l_{b,t} \tag{14}$$

Where n_a is calculated in the same manner as illustrated earlier in the creation of initial portfolio. $E_{bank,t}$ and $E_{banks,t}$. are maximum funds given respectively minimal reserves and capital adequacy requirements. Further, maximum available demand for liquidity is calculated and set together with available loans:

$$LA_{bank,t} = min\left[\sum l_{d,t}\, , min(AF_{banks,t})\right] \tag{15}$$

$$\{l_{d,t} \in B_{bank} | l_d = 0\}$$

Where B_{bank} are borrowers linked to a given bank and l_d is the loan in demand, for which 0 indicates that the borrower is not in debt. When $l_d > min(AF_{banks,t})$ the eligible borrowers are given loans in a random fashion. Note, that, without the loss of generality, the share of the market for particular bank is usually constant, thus banks cannot compete between themselves in that manner, nonetheless, there are other mechanisms described that incorporate competition or in other way simulate it.

Actual simulation was performed with following variables. Simulation takes 100 periods of agents, including 10 banks, 10 000 households and 20 000 borrowers. Number of borrowers is much higher than households for banks to not face market size constraint in the simulation. Households may withdraw their deposit of a unit value, with minimal probability of 0.01 and maximal 0.08. Borrowers may default with their loans of unit value with minimal probability of 0.04 and maximal 0.08. Banks start simulation with initial equity equal to 80 and try to increase it and then stabilize on 2.5 multiple of capital adequacy ratio, which is 0.06. After gathering deposits, banks must respect minimal reserve ratio equal to 0.035 but, try to stabilize it on twice that amount. Deposits yield interest times deposit premium, respectively, 1.007 and 1.07. Analogically, loans generate revenue to the banks equal to interest times loan margin of 1.1 and after generating income are lowered with 18% income tax rate. Recovery rate of these loans amount to 0.4. When banks lack liquidity and have to sell or securitize their loans immediately, they sell them with 0.8 of principal value. Depositors who allocate their funds to banks who generate losses during last period, may withdraw their deposits with additional 0.04 percentage point probability. Next chapter will describe how simulated banking sector in its aggregated values is going to react to exogenous shocks affecting their equilibrium. Three shocks will be introduced into the model with magnitude and time of choice.

3. Analysis and inference

This chapter shows how banks react to artificially introduced shocks in capital adequacy ratio, loan default probability and minimal reserve ratio. Every variable of the model might be influenced according to one's will, however, following variable were chosen because are of utter interest among practitioners as well as theorists. More extensive analysis can be carried out, since the whole model is too comprehensive to be exploited in one paper. Fitted regression on charts is a local polynomial regression with $\alpha = 0.75$ and confidence interval $\gamma = 0.95$. Their purpose is solely to help clarify the underlying trend of the variable. Fig. 1 chart shows the effect on sharp increase in capital adequacy ratio by 0.02 in a $t = 40$, soon after the equilibrium of the sector have been established. The shock had an expected effect on equity and during approximately 15 periods the banks increased enough equity to be in line with new regulations. Medium term relation of sharp increase of CAR is rather non-linear, raising it by 1/3 increased the equity in equilibrium by almost ½. Effect on dividends is also expected, banks postpone their dividends until reach target level of equity. Profitability measured as return on equity is had an interesting reaction. The initial trend is reversed when it hits on approx. 0.25, and then it slowly decreases until the end of simulation. It takes longer for ROE to form equilibrium again than it is for other variables. The shock has similar effect when the starting CAR of banks is lowered to only 0.04. Trends of equity and dividends is reversed but the profitability reversion is smoothed.

Subsequent shock in probability of default comes from the modestly modelled here real sphere of economy, thus, this effect usually is correlated with changes in other variables such as value of deposit. Although it is even more essential to analyze it, for there is less control over this variable than over the others by policymakers[14]. In every way, the effect of shock is sudden. The raise in probability of default of 0.09 had significant effect on systematic risk, given the CAR of 0.06 for banks. Level of equity dropped by as much as ¼ and it took almost whole simulation to recover. Reserves held by banks suffer in similar way, although it stabilizes after reaching its peak and are recovering faster. Income rapidly recovered from

[14] M. Markiewicz, *The concentration and competition in the banking sectors of the Baltic States in the context of a crisis* [in:] *Recovery of the Baltic States after the Global Financial Crisis: Necessity and Strategies*, Supplement 1 to the Annual Report 2013: Working Papers of the Research Project on the Baltic States, 2013, p. 12–16.

deep loss of the sector and had a minor effect on dividend's long-term trend. Bank's dividend policy was discontinued for a while and had not been for the shock, the trend would be almost linear for whole simulation. For a CAR at 0.06, the threshold increase of probability of default is around 0.15, after which most of the agents go bankrupt. Higher initial CAR has diminishing effect on safety of the sector.

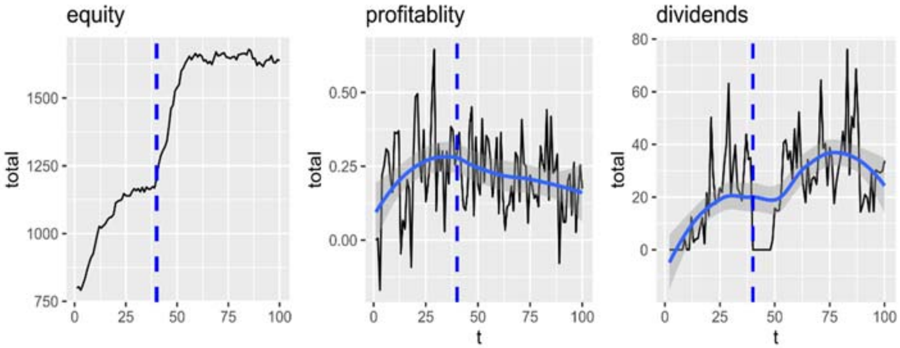

Fig. 1. Effect of regulatory shock on chosen variables of banking sector[15]

Source: Author's own calculation. Made with ggplot2 package. H. Wickham, *ggplot2: Elegant Graphics for Data Analysis*, Springer-Verlag, New York 2016, p. 20–21.

Last shock analyzes changes in a monetary policy instrument, which is minimal reserve ratio. Relatively, this is the biggest change, with ca. 85% increase, from 0.035 to 0.065. The most direct changes are in reserves held. Had not been because of the liquidity assistance, the banks would not have increase it that fast. Seemingly, the change in MRR, in some way accelerated the forming of an equilibrium from the beginning of simulation but on a higher level. Even though, the demand in the model is assumed to be rather unlimited, it is easier for banks to raise reserves than to gradually reach to the target level from overliquidity. Total equity, despite experiencing significantly higher variability after the shock, continued its pre-shock trend. Similarly, revenue also had higher volatility, whose reason is rather troublesome to identify. Profitability, likewise to the change in CAR, have also decreased after the shock. Both of which is to be expected.

[15] Blue dashed line indicates moment of shock introduction. Blue solid line is a fitted loess regression.

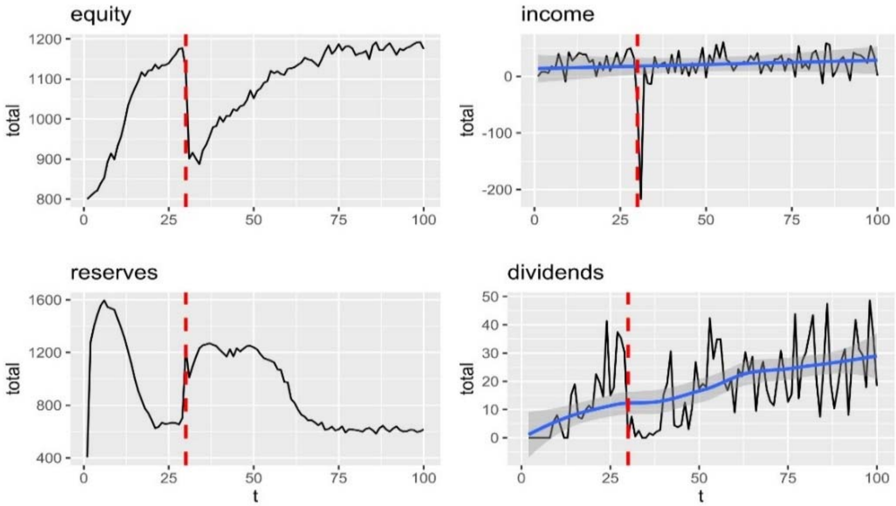

Fig. 2. Consequences of raising probability of default in banking sector by 9%[16]

Source: Author's own calculation. Made with ggplot2 package. H. Wickham, *ggplot2: Elegant Graphics for Data Analysis*, Springer-Verlag, New York 2016, p. 20–21.

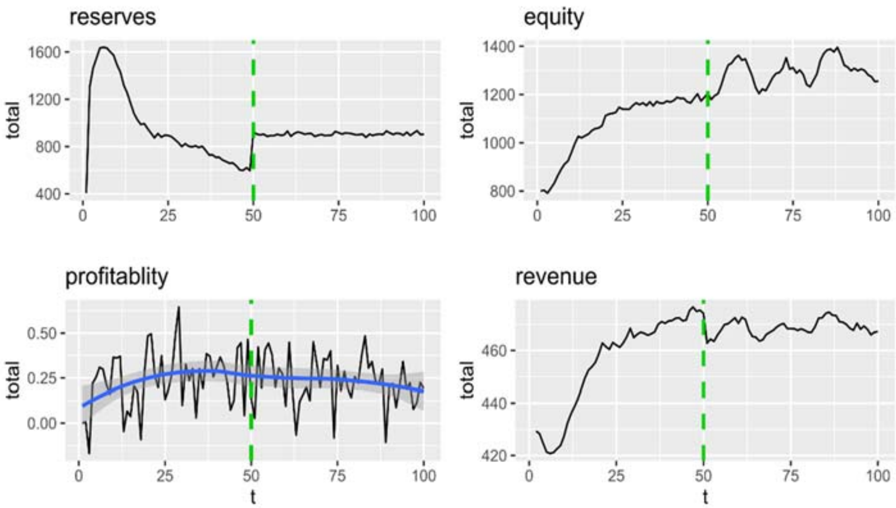

Fig. 3. Changes of chosen variables after increase in minimal reserve ratio[17]

Source: Author's own calculation. Made with ggplot2 package. H. Wickham, *ggplot2: Elegant Graphics for Data Analysis*, Springer-Verlag, New York 2016, p. 20–21.

16 Red dashed line indicates moment of shock. Blue solid line is loess fit with grey confidence interval.

17 Moment of shock indicated by a green dashed line. Blue solid line is loess fit with grey confidence interval.

Conclusions

Herein paper provides comprehensive yet very general model of banking sector with the agent-based modelling approach. The model is used to assess the adverse exogenous shocks on banking sector and its systematic risk. What is unique about this particular approach is the way every mechanism of returning to equilibrium can be shown as well as new state the market will achieve. Outcomes of the analysis are mostly in line with current state of empirical research, although they differ in some exhibited behaviors. Such as accelerated forming of equilibrium after raising MRR or non-linear relation of CAR level and equities.

The paper also demonstrates attractivity of agent-based modelling as a substitute approach to dynamic stochastic general equilibrium models applied in most of the notable economic research institutions. Thanks to the similar holistic approach to modelling economy, possibility to incorporate stylized fact in a clear manner and high degree of interpretability, these models seems to be interchangeable. The ABM approach though, do not constrain the researcher to assume that the economy will move toward predetermined equilibrium.

References

Chan-Lau J.A, *ABBA: An Agent-Based Model of the Banking System*, IMF Working Paper, WP/17/136, 2017.

Dickens R.N., et. al., *Bank Dividend Policy: Explanatory Factors*, "Quarterly Journal of Business and Economics" 2002, vol. 41, no. 1/2.

Farmer J., Foley D., *The economy needs agent-based modelling*. "Nature" 2009, no. 460.

Galí J., *Some scattered thoughts on DSGE models* [in:] *DSGE Models in the Conduct of Policy: Use as intended*, CEPR Press, London 2017.

Hamill L., Gilbert N., *Agent-Based Modelling in Economics*, Wiley, Hoboken 2015.

Krugman. P, *The State of Macro Is Sad (Wonkish)*, The New York Times, 12.08.2016, https://krugman.blogs.nytimes.com/2016/08/12/the-state-of-macro-is-sad-wonkish/.

LeBaron B., *A Real Minsky Moment in an Artificial Stock Market,* International Business School, Brandeis University Working Paper, 2012.

Markiewicz M., *The concentration and competition in the banking sectors of the Baltic States in the context of a crisis*, Recovery of the Baltic States after the Global Financial Crisis: Necessity and Strategies, Supplement 1 to the Annual Report: Working Papers of the Research Project on the Baltic States, 2013.

North M., Macal C.M., *Managing Business Complexity: Discovering Strategic Solutions with Agent-Based Modeling and Simulation*, Oxford University Press, Oxford 2007.

Poledna S., Miesse M.G., Hommes C., *Economic Forecasting with an Agent-based Model*, Available at SSRN: https://ssrn.com/abstract=3484768, 2019.

Wickham H., *ggplot2: Elegant Graphics for Data Analysis*, Springer-Verlag New York 2016.

Romer P., *The Trouble With Macroeconomics*, Delivered January 5, 2016 as the Commons Memorial Lecture of the Omicron Delta Epsilon Society.

Stiglitz J. E., *Where Modern Macroeconomics Went Wrong*, NBER Working Paper 2017, no. 23795.

Smets F., Wouters R., *Forecasting with a Bayesian DSGE model: an application to the euro area*, "JCMS: Journal of Common Market Studies" 2004, vol. 42 (4).

Smets F., Wouters R., *Shocks and Frictions in US Business Cycles: A Bayesian DSGE approach*, "American Economic Review" 2007, vol. 97, no. 3.

Summary

This paper presents an agent-based model of banking sector, which includes three kinds of heterogenous agents – households, borrowers and banks. Households provide funds to the banking sector via deposits and are changing their bank of choice stochastically. Borrowers are main source of demand for liquidity in this system, which they utilize for a risky undertaking, that may not succeed, thus defaulting on a loan. And finally banks act as an intermediary between two previous agents and manage their simple balance sheet. Agents interact with each other, establishing a time-varying equilibrium, that is able to receive an endogenous macroeconomic shock and return to the equilibrium, which may not be in the same place or may exhibit different characteristics depending on type of the shock. The simulation introduces shocks to the three variables, namely minimal reserve ratio, probability of default and capital adequacy ratio. The work also compares drawbacks and advantages of agent-based models to the commonly used equation-based models, such as dynamic stochastic general equilibrium models.

Keywords: macroeconomics, banking sector, agent-based modelling, macroeconomic shocks, computational economics

SYMULOWANIE SZOKÓW MAKROEKONOMICZNYCH W AGENTOWYM MODELU SEKTORA BANKOWEGO

Streszczenie

Artykuł omawia model sektora bankowego stworzony w oparciu o programowanie agentowe. Model zawiera trzy rodzaje agentów: gospodarstwa domowe, kredytobiorców oraz banki. Każdy agent ma przypisane zestawy zachowań, które reagują na otoczenie, zawierają interakcję między agentami lub mają zaprogramowane bierne czynności. Wszystkie zachowania agentów odzwierciedlają stylizowane fakty, przedstawione przez dorobek nauk ekonomicznych, aby odpowiednio symulować system ekonomiczny. Model jest poddawany egzogenicznym szokom w postaci zwiększenia prawdopodobieństwa nieuregulowania kredytu, wymogów kapitałowych oraz minimalnej stopy rezerw. Głównym obiektem analizy są banki, których reakcje na szoki są w większości zgodne z literaturą ekonomiczną. Mniej oczekiwanymi reakcjami, które zaszły w modelu jest przyspieszone osiągnięcie równowagi rynkowej przez banki po zwiększeniu rezerw minimalnych oraz nie-liniowa zależność między szokiem regulacyjnym a poziomem kapitałów własnych banku. Jak wykazuje powyższa publikacja, przedstawione podejście programowania agentowego przy modelowaniu zjawisk ekonomicznych może być ciekawą i przydatną alternatywą do szeroko wykorzystywanych w praktyce polityki gospodarczej modeli DSGE.

Słowa kluczowe: makroekonomia, sektor bankowy, modelowanie agentowe, szoki makroekonomiczne, ekonomia obliczeniowa