COMPUTER RESEARCH AND MODELING
2024 VOL. 16 NO. 4 P. 1023–1032
DOI: 10.20537/2076-7633-2024-16-4-1023-1032

MODELS OF ECONOMIC AND SOCIAL SYSTEMS

UDC: 519.6+336.7

Assessing the impact of deposit benchmark interest rate on banking loan dynamics

M. F. Ansori[1,a], H. Al Jasir[2], A. H. Sihombing[2], S. M. Putra[2], D. A. Nurfaizah[2], E. Nurulita[2]

[1]Department of Mathematics, Faculty of Science and Mathematics, Universitas Diponegoro, Jl. Prof. Jacub Rais, 50275, Semarang, Indonesia
[2]Mathematics Undergraduate Study Program, Universitas Diponegoro, Jl. Prof. Jacub Rais, 50275, Semarang, Indonesia

E-mail: [a] mochfandiansori@lecturer.undip.ac.id (corresponding author)

Received 18.01.2024, after completion — 07.06.2024.
Accepted for publication 11.06.2024.

Deposit benchmark interest rates are a policy implemented by banking regulators to calculate the interest rates offered to depositors, maintaining equitable and competitive rates within the financial industry. It functions as a benchmark for determining the pricing of different banking products, expenses, and financial choices. The benchmark rate will have a direct impact on the amount of money deposited, which in turn will determine the amount of money available for lending. We are motivated to analyze the influence of deposit benchmark interest rates on the dynamics of banking loans. This study examines the issue using a difference equation of banking loans. In this process, the decision on the loan amount in the next period is influenced by both the present loan volume and the information on its marginal profit. An analysis is made of the loan equilibrium point and its stability. We also analyze the bifurcations that arise in the model. To ensure a stable banking loan, it is necessary to set the benchmark rate higher than the flip value and lower than the transcritical bifurcation values. The confirmation of this result is supported by the bifurcation diagram and its associated Lyapunov exponent. Insufficient deposit benchmark interest rates might lead to chaotic dynamics in banking lending. Additionally, a bifurcation diagram with two parameters is also shown. We do numerical sensitivity analysis by examining contour plots of the stability requirements, which vary with the deposit benchmark interest rate and other parameters. In addition, we examine a nonstandard difference approach for the previous model, assess its stability, and make a comparison with the standard model. The outcome of our study can provide valuable insights to the banking regulator in making informed decisions regarding deposit benchmark interest rates, taking into account several other banking factors.

Keywords: chaos, deposit benchmark rate, sensitivity analysis, two-parameter bifurcation

Citation: *Computer Research and Modeling*, 2024, vol. 16, no. 4, pp. 1023–1032.

This research is supported by the Faculty of Science and Mathematics, Universitas Diponegoro through Sumber Dana Selain APBN FSM UNDIP with grant number 27.III.B/UN7.F8/PP/II/2024.

Introduction

Deposit benchmark interest rates serve as a reference point for pricing various financial products, determine the cost of funds for banks, and impact monetary policy decisions. These rates, also referred to as base rates or reference rates, represent the minimum return offered by financial institutions on deposit accounts and serve as a key indicator of the current interest rate environment. The establishment of deposit benchmark interest rates provides financial market transparency and stability. These rates serve as a benchmark for pricing a vast array of financial products, including loans, mortgages, and bonds, influencing the cost of financing for individuals and businesses. These rates are used by financial institutions to compute the interest paid to depositors, ensuring fair and competitive rates across the industry. Further empirical evidence regarding factors that may influence deposit interest rate arrangement is more notable because it is commonly assumed that alterations in reference rates are spread relatively quickly to retail interest rates and then into the real economy [Anderson, Ashton, Hudson, 2014].

The study of the role of deposit interest rates on several aspects of the banking industry has been done by various approaches. The impact of market structure changes and bank-specific factors on the deposit interest rates that a bank offers in a particular local market are studied using an empirical model [Rosen, 2007]. Three different models of deposit rate determination are estimated by employing deposit interest rate quantification that is built from accounting data at the bank level for an extensive cross-sectional sample of banks for each of three different years [Hannan, Prager, 2006]. A determination of whether the Japanese bank deposit markets exhibit geographic segmentation is estimated by extending to which changes in market interest rates are reflected in deposit interest rates [Uchino, 2014]. Historical bank-level data is used to investigate the impact of deposit rate ceilings on the expansion of loans in commercial banks [Koch, 2015]. A logit model is used to link aloft deposit interest rates to bank bankruptcy, where aloft a deposit interest rate is a dependable indicator of risk-taking [Kraft, Galac, 2007].

The benchmark rate will affect the deposit inflows directly, and this cash will affect how much money can be turned into a loan. This motivates us to assess the impact of deposit benchmark interest rates on lending dynamics. Several ways to address the industrial banking problem are possible by using mathematical models. For example, a constrained optimization portfolio of the bank balance sheet to analyze the impact of a macroprudential policy on the bank's decision-making [Gunadi, Harun, 2011; Satria, Harun, Taruna, 2016], a dynamical system of bank balance sheet to study the dynamics of banking variables such as deposits, loans, equity, and reserve requirements by employing banking data [Sumarti et al., 2018; Ansori, Sidarto, Sumarti, 2019b; Ansori, Sidarto, Sumarti, 2019a; Ansori et al., 2021c], a network approach to study a macroprudential instrument and its impact on the banking system stability [Ansori et al., 2021a], and a single difference equation or a system of two difference equations of banking loan variables to survey the banking policies such as capital adequacy ratio, reserve requirements, and macroprudential policy [Fanti, 2014; Ansori et al., 2021a; Brianzoni, Campisi, 2021; Brianzoni, Campisi, Colasante, 2022; Ansori et al., 2021b; Ansori, Theotista, Winson, 2023; Ansori, Ashar, 2023; Ansori, Theotista, Febe, 2023; Ashar, Ansori, Fata, 2023]. For this purpose, we follow the latter model to investigate the role of deposit benchmark interest rates.

Model formulation

Suppose a bank balance sheet identity is given below:

$$L + R = D + E, \tag{1}$$

where L is loan, R is reserve requirement, D is deposit, and E is equity.

The reserve requirement is a monetary policy implemented by the central bank to mandate that each bank holds a specific proportion of its deposits at the central bank. This policy is formulated as an integral component of both monetary policy and macro-prudential policy. Thus, we have

$$R = \rho D, \quad 0 < \rho < 1. \tag{2}$$

Equity is required to adhere to the capital adequacy ratio regulation, which mandates that its ratio with risk-weighted assets must exceed a specific percentage. Given that this article only considers two asset variables, namely, loan and reserve requirement, it follows that the risk-weighted asset is solely the loan. In order to further simplify the model, we make the assumption that the equity is equivalent to

$$E = \kappa L, \quad 0 < \kappa < 1. \tag{3}$$

In this model, the deposit is assumed to be calculated after all variables are determined. Thus,

$$D = \frac{1-\kappa}{1-\rho} L. \tag{4}$$

The loan follows a gradient adjustment procedure [Bischi et al., 2010], where the following period's loan amount is determined based on the present loan and its marginal profit. It forms a difference equation as follows [Fanti, 2014]:

$$L_{t+1} = L_t + \alpha_L L_t \frac{\partial \pi_t}{\partial L_t}, \tag{5}$$

where α_L is an adjustment rate, and π_t is the bank's profit which is calculated below:

$$\pi_t = r_{L,t} L_t - r_{D,t} D_t - r_E E_t - C_t, \tag{6}$$

where $r_{L,t} = a_L - b_L L_t$ is the inverse linear loan interest rate, $r_{D,t} = a_D + b_D D_t$ is the inverse linear deposit interest rate [Klein, 1971; Monti, 1972], r_E is constant equity cost, and $C_t = c_D D_t + c_L L_t$ is the linear operational cost. All parameters are positive.

Next, we assume that the parameter of the deposit interest rate is defined as $a_D = a_{D0} - a_{D1}$, where a_{D0} is the deposit benchmark interest rate set by the central bank. Usually, the banking industry establishes its deposit interest rate at a level below the benchmark set by the central bank. The parameter a_{D0} is the focal point of our investigation since we aim to examine its influence on the dynamics of banking loans.

By those assumptions, the bank's profit becomes

$$\pi_t = \left(a_L - \left[r_E \kappa + c_L + (a_{D0} - a_{D1} + c_D)\left(\frac{1-\kappa}{1-\rho}\right)\right]\right) L_t - \left[b_L + b_D \left(\frac{1-\kappa}{1-\rho}\right)^2\right] L_t^2. \tag{7}$$

Thus, the banking loan model in (5) becomes

$$L_{t+1} = L_t + \alpha_L L_t \left(a_L - \left[r_E \kappa + c_L + (a_{D0} - a_{D1} + c_D)\left(\frac{1-\kappa}{1-\rho}\right)\right] - 2\left[b_L + b_D \left(\frac{1-\kappa}{1-\rho}\right)^2\right] L_t\right). \tag{8}$$

Local stability and bifurcations analysis

Model (8) has two equilibria: a zero equilibrium $L^*_{(0)} = 0$ and a positive equilibrium

$$L^*_{(1)} = \frac{a_L - \left[r_E\kappa + c_L + (a_{D0} - a_{D1} + c_D)\left(\frac{1-\kappa}{1-\rho}\right)\right]}{2\left[b_L + b_D\left(\frac{1-\kappa}{1-\rho}\right)^2\right]}.$$

The positive equilibrium will have a positive value if it fulfills the following criterion:

$$a_L > r_E\kappa + c_L + (a_{D0} - a_{D1} + c_D)\left(\frac{1-\kappa}{1-\rho}\right). \tag{9}$$

The subsequent theorem asserts the local stability of the equilibria.

Theorem 1. *The zero equilibrium is unstable. Furthermore, the positive equilibrium is considered to be locally asymptotically stable if*

$$a_{D0} > \left(a_L - \left(\frac{2}{\alpha_L} + r_E\kappa + c_L\right)\right)\left(\frac{1-\rho}{1-\kappa}\right) + a_{D1} - c_D. \tag{10}$$

Proof. To begin with, let us consider the loan model expressed in equation (8) and rephrase it as $L_{t+1} = f(L_t)$. The function f is differentiated once to obtain $f'(L_t) = 1 + \alpha_L\left(a_L - r_E k - c_L + (a_{D1} - a_{D0} - c_D)\left(\frac{1-k}{1-p}\right)\right) - 4\alpha_L\left(b_L + b_D\left(\frac{1-k}{1-p}\right)^2\right)L_t$. Based on [Alligood, Sauer, Yorke, 1996], equilibrium L^* is locally asymptotically stable if $|f'(L^*)| < 1$. In the case of $L^*_{(0)}$, we have $f'\left(L^*_{(0)}\right) = 1 + \alpha_L\left(a_L - \left[r_E\kappa + c_L + (a_{D0} - a_{D1} + c_D)\left(\frac{1-\kappa}{1-\rho}\right)\right]\right) > 1$, because we have the positivity condition in (9). Thus, the zero equilibrium is not stable. In the case of positive equilibrium, it is clear that $f'\left(L^*_{(1)}\right) = 1 - \alpha_L\left(a_L - \left[r_E\kappa + c_L + (a_{D0} - a_{D1} + c_D)\left(\frac{1-\kappa}{1-\rho}\right)\right]\right) < 1$. However, $f'\left(L^*_{(1)}\right) > -1$ if $a_{D0} > \left(a_L - \left(\frac{2}{\alpha_L} + r_E\kappa + c_L\right)\right)\left(\frac{1-\rho}{1-\kappa}\right) + a_{D1} - c_D$. □

Bifurcations occur in the loan model (8) when the absolute value of the derivative of f with respect to L at L^* is equal to 1. The transcritical bifurcation occurs when $f'(L^*)$ is equal to 1, while the flip (doubling-period) bifurcation occurs when $f'(L^*)$ is equal to -1. The subsequent theorem establishes the significance of those bifurcations.

Theorem 2. *The positive equilibrium's stability is compromised by transcritical and flip bifurcations when the deposit benchmark interest rate is equal to* $a_{D0} = a^T_{D0}$ *where* $a^T_{D0} = \left(a_L - \left(r_E\kappa + c_L\right)\right)\left(\frac{1-\rho}{1-\kappa}\right) + a_{D1} - c_D$ *and* $a_{D0} = a^F_{D0}$ *where* $a^F_{D0} = \left(a_L - \left(\frac{2}{\alpha_L} + r_E\kappa + c_L\right)\right)\left(\frac{1-\rho}{1-\kappa}\right) + a_{D1} - c_D$, *respectively. In addition, the positive equilibrium is stable and exists when* $a^F_{D0} < a_{D0} < a^T_{D0}$.

Proof. The values of the bifurcations can be quickly found by solving the equation $|f'(L^*)| = 1$. The inequality $a^F_{D0} < a_{D0} < a^T_{D0}$ may be deduced from Theorem 1, which states that $a_{D0} > a^F_{D0}$, and the fact that $a^F_{D0} < a^T_{D0}$. □

The deposit benchmark interest rate ranges from 0 to 1. Therefore, for economic significance, both the flip and transcritical bifurcation values must likewise fall within the range of 0 and 1. If $0 < a^F_{D0} < 1$, then $c_D - \left(a_L - \left(r_E\kappa + c_L\right)\right)\left(\frac{1-\rho}{1-\kappa}\right) < a_{D1} < 1 + c_D - \left(a_L - \left(r_E\kappa + c_L\right)\right)\left(\frac{1-\rho}{1-\kappa}\right)$. Meanwhile, the condition $0 < a^T_{D0} < 1$ implies $\frac{2}{a_L - \left[(c_D - a_{D1})\left(\frac{1-\kappa}{1-\rho}\right) + r_E\kappa + c_L\right]} < \alpha_L < \frac{2}{a_L - \left[(1 + c_D - a_{D1})\left(\frac{1-\kappa}{1-\rho}\right) + r_E\kappa + c_L\right]}$.

An additional interesting analysis can be conducted by examining the partial derivative of the transcritical and flip bifurcations with respect to the model's parameters. This allows us to assess the extent to which the parameters influence the values of the bifurcations.

For the transcritical bifurcation, we have,

$$\frac{\partial a_{D0}^T}{\partial a_{D1}} = 1 > 0, \quad \frac{\partial a_{D0}^T}{\partial a_L} = \frac{1-\rho}{1-\kappa} > 0, \quad \frac{\partial a_{D0}^T}{\partial r_E} = -\frac{\kappa(1-\rho)}{1-\kappa} < 0,$$

$$\frac{\partial a_{D0}^T}{\partial \rho} = -\frac{a_L - (r_E\kappa + c_L)}{1-\kappa} < 0, \quad \frac{\partial a_{D0}^T}{\partial \kappa} = (a_L - (r_E\kappa + c_L))\frac{(1-\rho)}{(1-\kappa)^2} > 0,$$

$$\frac{\partial a_{D0}^T}{\partial c_D} = -1 < 0, \quad \frac{\partial a_{D0}^T}{\partial c_L} = -\frac{1-\rho}{1-\kappa} < 0.$$

In the case of the flip bifurcation, we have,

$$\frac{\partial a_{D0}^F}{\partial a_{D1}} = 1 > 0, \quad \frac{\partial a_{D0}^F}{\partial a_L} = \frac{1-\rho}{1-\kappa} > 0, \quad \frac{\partial a_{D0}^F}{\partial r_E} = -\frac{\kappa(1-\rho)}{1-\kappa} < 0,$$

$$\frac{\partial a_{D0}^F}{\partial \rho} = -\frac{a_L - \left(\frac{2}{\alpha_L} + r_E\kappa + c_L\right)}{1-\kappa} < 0, \quad \frac{\partial a_{D0}^F}{\partial \kappa} = \left(a_L - \left(\frac{2}{\alpha_L} + r_E\kappa + c_L\right)\right)\frac{(1-\rho)}{(1-\kappa)^2} > 0,$$

$$\frac{\partial a_{D0}^F}{\partial c_D} = -1 < 0, \quad \frac{\partial a_{D0}^F}{\partial c_L} = -\frac{1-\rho}{1-\kappa} < 0,$$

$$\frac{\partial a_{D0}^F}{\partial \alpha_L} = \frac{2}{\alpha_L^2}\left(\frac{1-\rho}{1-\kappa}\right) > 0.$$

In order to ensure the stability of the loan, the regulator or bank can adjust the other parameters accordingly. If the partial derivative of a_{D0}^F is negative, they may set the other parameters to have higher values. Conversely, if the partial derivative of a_{D0}^F is positive, they may set the other parameters to have lower values.

Numerical simulations

To validate the analytical findings, we conduct a series of simulations including the bifurcation diagram, the Lyapunov exponent associated with the bifurcation diagram, a two-parameter bifurcation diagram, and sensitivity analysis. All simulations utilize the parameter values specified in Table 1. These values are selected for simulation purposes only, yet they still fulfill all the requirements stated in the previous section.

Table 1. Parameters' value

Parameter	Description	Value
a_{D0}	Deposit benchmark interest rate	Vary
a_{D1}	Bank's deposit interest rate adjustment	0.01
b_D	Bank's deposit interest rate adjustment to the deposit volumes	0.05
a_L	Loan interest rate adjustment	0.2
b_L	Loan interest rate adjustment to the loan volumes	0.05
r_E	Rate of return of equity	0.05
ρ	Reserve requirement	0.12
κ	Capital adequacy ratio	0.08
c_D	Deposit's operating cost	0.05
c_L	Loan's operating cost	0.05
α_L	Speed of adjustment rate	5

The graph in Fig. 1, *a* illustrates the bifurcation of the deposit benchmark interest rate a_{D0}. We discover that reducing the value of a_{D0} leads to an increase in the loan equilibrium. Insufficient a_{D0} will result in complex dynamics behavior of loan expansion. The presence of chaos in this intricate dynamics can be demonstrated by a positive Lyapunov exponent, as indicated by the red dots in Fig. 1, *b*. To ensure the stability of the banking loan, it is necessary to fix the value of a_{D0} between the flip and transcritical bifurcation values.

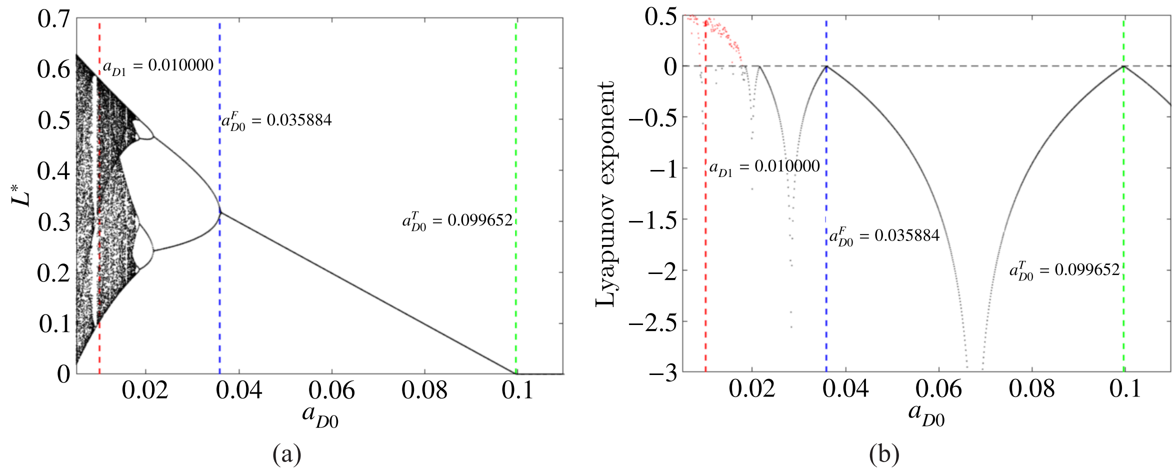

Figure 1. (a) Bifurcation diagram of a_{D0} and (b) the related Lyapunov exponent

Figure 2 displays a two-parameter bifurcation diagram of a_{D0} and a_{D1}, as well as a_{D0} and b_D, illustrating the joint impact of these parameters on the banking loan equilibrium's stability. The simulation is conducted using an algorithm suggested in [Ansori, Ashar, Fata, 2024]. The algorithm represents the parameter points that are coupled in blue, green, or red markers, depending on whether the banking loans are steady, periodic, or chaotic. The simulation allows us to view the specific location, represented by the blue region, where stable banking loans may be ensured.

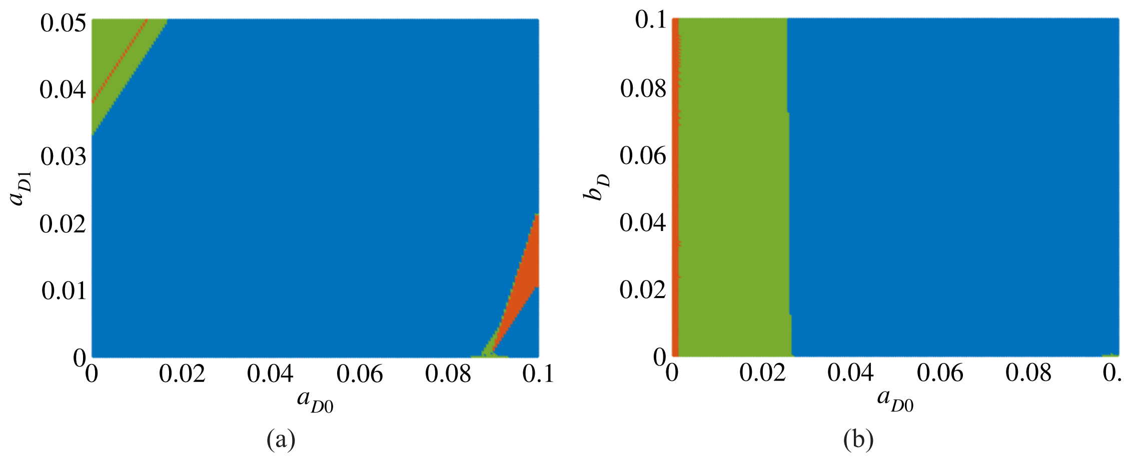

Figure 2. Two-parameter bifurcation diagram of (a) $a_{D0} - a_{D1}$ and (b) $a_{D0} - b_D$

The stability condition of the positive equilibrium $L^*_{(1)}$ in (10) is rewritten as S := $:= \frac{\left(a_L - \left(\frac{2}{\alpha_L} + r_E\kappa + c_L\right)\right)\left(\frac{1-\rho}{1-\kappa}\right) + a_{D1} - c_D}{a_{D0}} < 1$. Therefore, we can conclude that $L^*_{(1)}$ is locally asymptotically stable for $S < 1$. Now, we see S as a function with two variables, and our focus is on creating a contour plot of this function. In Fig. 3, we provide the contour plot of S for combinations of a_{D0} with the remaining

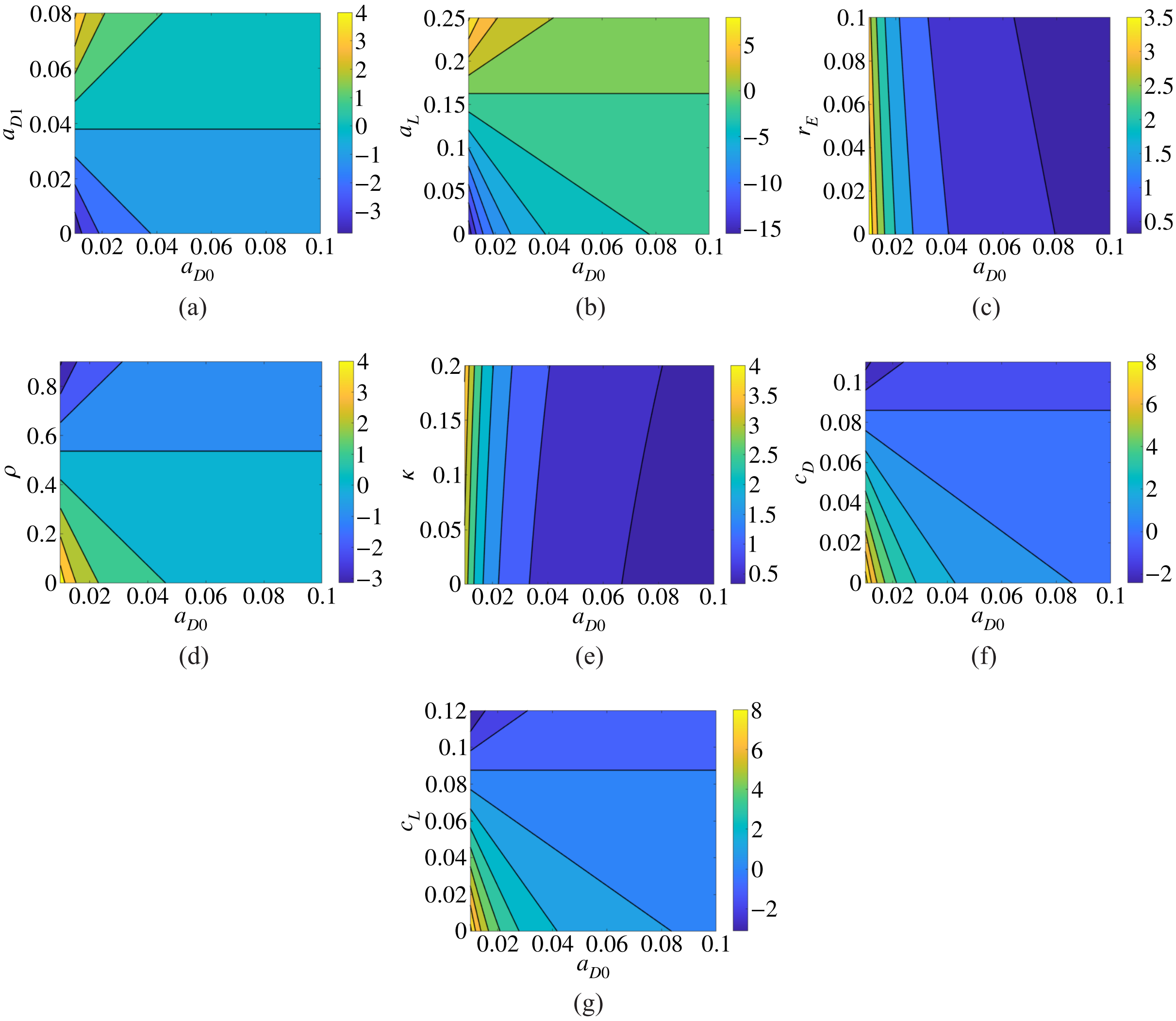

Figure 3. Contour plot of sensitivity function S as a function of two parameters: a_{D0} and (a) a_{D1}, (b) a_L, (c) r_E, (d) ρ, (e) κ, (f) c_D, and (g) c_L. The area with a heat color value of less than 1 means that the loan equilibrium is stable if the parameters' value is in there

parameters. Through analysis, we can identify the region in the contour plot where the spectrum has a value below 1, indicating the presence of stable banking loans.

Model with a nonstandard difference scheme

We modify the model (8) by using a nonstandard difference scheme [Mickens, 1994; Shabbir et al., 2019; Khan et al., 2022]. First, let us simplify the writing of the model (8) into

$$L_{t+1} = L_t + \alpha_L L_t(\Lambda - \Omega L_t), \tag{11}$$

where $\Lambda = a_L - \left[r_E\kappa + c_L + (a_{D0} - a_{D1} + c_D)\left(\frac{1-\kappa}{1-\rho}\right)\right]$ and $\Omega = 2\left[b_L + b_D\left(\frac{1-\kappa}{1-\rho}\right)^2\right]$. From (10) we know that $\Lambda > 0$, and since all parameters are positive, it follows that $\Omega > 0$.

The modification of the nonstandard difference scheme is by letting the term on the right-hand side of (11) that has a negative sign, i. e., $-\alpha_L\Omega L_t^2$, be changed into $-\alpha_L\Omega L_t L_{t+1}$. From this we have

$$L_{t+1} = \frac{(1 + \alpha_L\Lambda)L_t}{1 + \alpha_L\Omega L_t}. \tag{12}$$

The difference equation (12) has the same equilibrium points of the difference equation (8), that is,

$$L^*_{(0)} = 0 \quad \text{and} \quad L^*_{(1)} = \frac{\Lambda}{\Omega}.$$

Suppose the right-hand side of (12) is denoted by $g(L_t)$, then we have

$$g'(L_t) = \frac{1 + \alpha_L \Lambda}{(1 + \alpha_L \Omega L_t)^2}.$$

If we substitute $L^*_{(0)} = 0$ into $g'(L_t)$, we have $g'(0) = 1 + \alpha_L \Lambda > 1$. Thus, the equilibrium $L^*_{(0)} = 0$ is not stable. For the case of $L^*_{(1)} = \frac{\Lambda}{\Omega}$ we have $\left|g'\left(\frac{\Lambda}{\Omega}\right)\right| = \left|\frac{1}{1+\alpha_L\Lambda}\right| < 1$. Thus, the equilibrium $L^*_{(1)} = \frac{\Lambda}{\Omega}$ is locally asymptotically stable. Thus, according to this modified model, there is no bifurcation, since $g'\left(\frac{\Lambda}{\Omega}\right)$ is never equal to -1 or 1.

In Fig. 4, *a*, we illustrate the changes in banking loans by employing the model (8) and the nonstandard difference model (12) with varying values of α_L. It is important to remember that α_L represents a parameter that determines the speed of adjustment. The time series of the standard model is affected by the value of α_L, whereas the nonstandard difference model is not modified. However, Fig. 4, *b* demonstrates that an increase in the value of a_{D0} in the nonstandard model leads to a decrease in its equilibrium of banking loans.

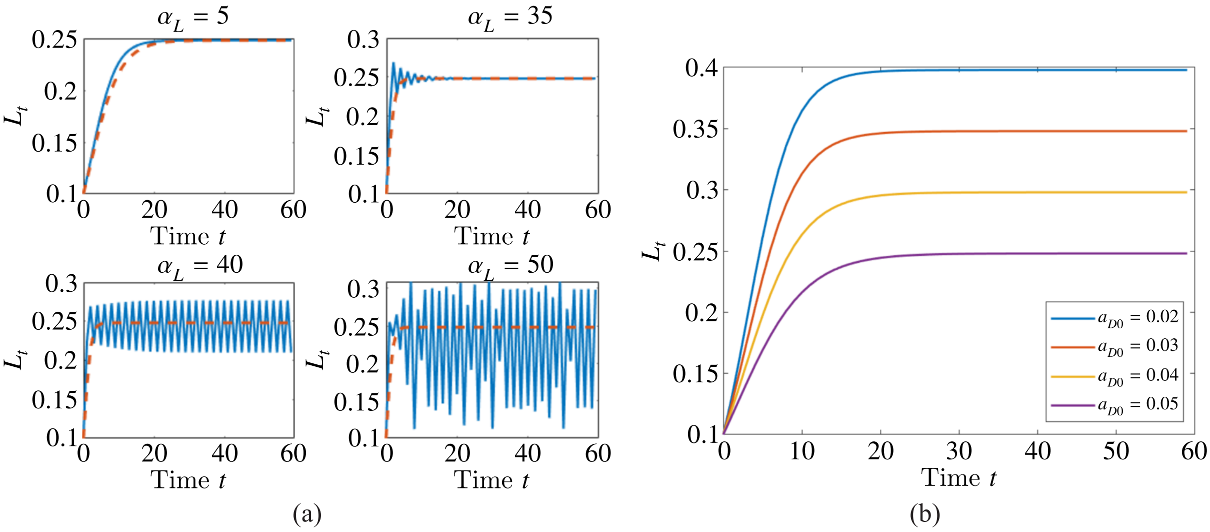

Figure 4. (a) Time series comparison between the standard difference model (blue line) and the nonstandard difference model (red dashed line) for different values of α_L. (b) The impact of different values of a_{D0} on the nonstandard difference model

Conclusions

According to the analytical and numerical findings, we discover that the deposit benchmark interest rate has a significant impact on the dynamics of banking loans. Initially, the regulator should contemplate establishing the benchmark rate at a level that is neither excessively elevated (as indicated by the transcritical bifurcation value) nor excessively low (as indicated by the flip bifurcation value). This outcome is consistent with the findings reported in [Ansori, Ashar, Fata, 2024]. Furthermore, an elevated benchmark rate will result in a decrease in the growth of banking loans. The regulator can utilize sensitivity analysis to adjust the regulation of the benchmark rate in response to fluctuations in other factors within the banking industry. The change aims to ensure the stability of banking loans. The scientific potential of our proposed model can be enhanced by incorporating nonlinear, stochastic, or fractional interest rates, as recommended in other academic works [Brianzoni, Campisi, Colasante, 2022; Huang, Jiang, Wang, 2020; Zhu, 2015].

References

Alligood K., Sauer T., Yorke J. Chaos: an introduction to dynamical systems. — New York: Springer-Verlag, 1996.

Anderson R. D. J., Ashton J. K., Hudson R. S. The influence of product age on pricing decisions: An examination of bank deposit interest rate setting // Journal of International Financial Markets, Institutions and Money. — 2014. — Vol. 31. — P. 216–230. — https://doi.org/10.1016/j.intfin.2014.03.010

Ansori M. F., Ashar N. Y. Analysis of loan benchmark interest rate in banking loan dynamics: bifurcation and sensitivity analysis // Journal of Mathematics and Modeling in Finance. — 2023. — Vol. 3, No. 1. — P. 191–202. — https://doi.org/10.22054/jmmf.2023.74976.1098

Ansori M. F., Ashar N. Y., Fata H. K. Logistic map-based banking loan dynamics with central bank policies // Journal of Applied Nonlinear Dynamics. — 2024 (in press).

Ansori M. F., Sidarto K. A., Sumarti N. Logistic models of deposit and loan between two banks with saving and debt transfer factors // AIP Conference Proceedings. — 2019a. — Vol. 2192. — DOI: 10.1063/1.5139148

Ansori M. F., Sidarto K. A., Sumarti N. Model of deposit and loan of a bank using spiral optimization algorithm // Journal of the Indonesian Mathematical Society. — 2019b. — Vol. 25, No. 3. — P. 292–301.

Ansori M. F., Sumarti N., Sidarto K. A., Gunadi I. An algorithm for simulating the banking network system and its application for analyzing macroprudential policy // Computer Research and Modeling. — 2021a. — Vol. 13, No. 6. — P. 1275–1289. — DOI: 10.20537/2076-7633-2021-13-6-1275-1289

Ansori M. F., Sumarti N., Sidarto K. A., Gunadi I. Analyzing a macroprudential instrument during the COVID-19 pandemic using border collision bifurcation // Revista Electrónica de Comunicaciones y Trabajos de ASEPUMA Rect@. — 2021b. — Vol. 22, No. 2. — P. 113–125. — DOI: 10.24309/recta.2021.22.2.04

Ansori M. F., Sumarti N., Sidarto K. A., Gunadi I. Dynamics of bank's balance sheet: a system of deterministic and stochastic differential equations approach // International Journal of Mathematics and Computer Science. — 2021c. — Vol. 16, No. 3. — P. 871–884.

Ansori M. F., Theotista G., Febe M. The influence of the amount of premium and membership of IDIC on banking loan procyclicality: a mathematical model // Advances in Dynamical Systems and Applications. — 2023. — Vol. 18, No. 2. — P. 111–123. — http://www.ripublication.com

Ansori M. F., Theotista G., Winson. Difference equation-based banking loan dynamics with reserve requirement policy // International Journal of Difference Equations. — 2023. — Vol. 18, No. 1. — P. 35–48.

Ashar N. Y., Ansori M. F., Fata H. K. The effects of capital policy on banking loan dynamics: aËdifference equation approach // International Journal of Difference Equations. — 2023. — Vol. 18, No. 1. — P. 267–279.

Bischi G.-I., Chiarella C., Kopel M., Szidarovszky F. Nonlinear oligopolies: stability and bifurcations. — Berlin: Springer-Verlag, 2010.

Brianzoni S., Campisi G. Dynamical analysis of a banking duopoly model with capital regulation and asymmetric costs // Discrete and Continuous Dynamical Systems – Series B. — 2021. — Vol. 26, No. 11. — P. 5807–5825. — DOI: 10.3934/DCDSB.2021116

Brianzoni S., Campisi G., Colasante A. Nonlinear banking duopoly model with capital regulation: The case of Italy // Chaos, Solitons & Fractals. — 2022. — Vol. 160. — P. 112209. — DOI: 10.1016/J.CHAOS.2022.112209

Fanti L. The dynamics of a banking duopoly with capital regulations // Economic Modelling. — 2014. — Vol. 37. — P. 340–349. — DOI: 10.1016/J.ECONMOD.2013.11.010

Gunadi I., Harun C. A. Revitalising reserve requirement in banking model: An industrial organisation approach // SEACEN Occasional Papers. — 2011. — No. 51.

Hannan T. H., Prager R. A. Multimarket bank pricing: An empirical investigation of deposit interest rates // Journal of Economics and Business. — 2006. — Vol. 58, No. 3. — P. 256–272. — https://doi.org/10.1016/j.jeconbus.2005.07.004

Huang Z., Jiang T., Wang Z. On a multiple credit rating migration model with stochastic interest rate // Mathematical Methods in the Applied Sciences. — 2020. — Vol. 43. — P. 7106–7134. — DOI: 10.1002/mma.6435

Khan M. S., Samreen M., Ozair M., Hussain T., Elsayed E. M., Gómez-Aguilar J. F. On the qualitative study of a two-trophic plant-herbivore model // Journal of Mathematical Biology. — 2022. — Vol. 85, No. 34. — P. 1–35.

Klein M. A. A theory of the banking firm // Journal of Money, Credit, and Banking. — 1971. — Vol. 3. — P. 205–218.

Koch C. Deposit interest rate ceilings as credit supply shifters: bank level evidence on the effects of regulation q // Journal of Banking & Finance. — 2015. — Vol. 61. — P. 316-326.

Kraft E., Galac T. Deposit interest rates, asset risk and bank failure in Croatia // Journal of Financial Stability. — 2007. — Vol. 2, No. 4. — P. 312–336.

Mickens R. E. Nonstandard finite difference models of differential equations. — Singapore: World Scientific, 1994.

Monti M. Deposit, credit and interest rates determination under alternative objective functions // Mathematical methods in investment and finance / G. P. Szego, K. Shell (eds.). — Amsterdam, 1972.

Rosen R. J. Banking market conditions and deposit interest rates // Journal of Banking & Finance. — 2007. — Vol. 31, No. 12. — P. 3862–3884.

Satria D., Harun C., Taruna A. The macro-prudential aspects of loan-to deposit-ratio-linked reserve requirement // Applied Economics. — 2016. — Vol. 48, No. 1. — P. 24–34.

Shabbir M. S., Din Q., Safeer M., Khan M. A., Ahmad K. A dynamically consistent nonstandard finite difference scheme for a predator – prey model // Advances in Difference Equations. — 2019. — Vol. 2019, No. 381. — P. 1–17.

Sumarti N., Fadhlurrahman A., Widyani H. R., Gunadi I. The dynamical system of the deposit and loan volumes of a commercial bank containing interbank lending and saving factors // Southeast Asian Bulletin of Mathematics. — 2018. — Vol. 42. — P. 757–772.

Uchino T. Bank deposit interest rate pass-through and geographical segmentation in Japanese banking markets // Japan and the World Economy. — 2014. — Vol. 30. — P. 37–51.

Zhu Y. Uncertain fractional differential equations and an interest rate model // Mathematical Methods in the Applied Sciences. — 2015. — Vol. 38. — P. 3359–3368.