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Research paper

Analysis of loan benchmark interest rate in banking loan dynamics: bifurcation and sensitivity analysis

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Abstract:
One of central bank regulations that has direct impact on the banking industry is loan benchmark interest rate. Banks use it as a reference rate to determine their loan interest rate. In this paper, we study the role of loan benchmark interest rate on banking loan dynamics. The model is in the form of a difference equation that follows a gradient adjustment process. We study the loan equilibrium's stability via bifurcation theory. It is found that the benchmark rate must be set between the flip and transcritical values. Some numerical simulations are performed to confirm the analytical result. The stochastic case of the benchmark rate is also studied. In addition, we perform numerical sensitivity analysis of the benchmark rate with the model's other parameters.

Keywords: benchmark interest rate, banking loan, bifurcation, chaos, sensitivity analysis
MSC2010 Classification: 39A60, 39A33.

1 Introduction

Reference rates, usually referred to as benchmark rates, are publicly available interest rates that are updated on a regular basis. They serve as an effective foundation for other financial agreements, including mortgages, bank overdrafts, and other more intricate financial transactions. A benchmark rate is determined by a third party, typically to reflect the cost of borrowing money in various markets. They could, for instance, show how much it costs banks to borrow money from one another. Alternately, they can show how much it costs banks to borrow money from other institutions like money market funds, insurance firms, and pension funds. In every sector of the economy, people and organizations frequently use benchmark rates. For instance, banks employ them when making loans to private individuals or business clients. A bank may agree to lend money to a business at an agreed

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interest rate that is set at a specific benchmark rate plus 2 percent. In this case, the business would be required to pay interest that is 2 percent more than the benchmark rate at the time the loan was made. Therefore, the cost of the loan increases if the benchmark rate increases and decreases if the benchmark rate decreases. In this situation, the benchmark can serve as a trustworthy, impartial, and generally easy reference for all parties.

Studies have been conducted to look at the relationships between various financial factors and the benchmark interest rate. Duan et al. [17] investigated the benchmark interest rate's pattern by contrasting the intensity and an economic indicator, where the central bank-set benchmark interest rate is modelled using a Poisson process with stochastic intensity. Augustin et al. [13] studied about benchmark behavior after global financial crisis and demonstrated via no-arbitrage that even in the absence of frictions like balance sheet restrictions, convenience yield, and hedging demand, sovereign default risk explains negative swap spreads, and in their paper an equilibrium model that simultaneously accounts for macroeconomic fundamentals, the term structures of interest rates, and US credit default swap rates is used to support this argument. Kim and Shi [22] empirically examined the factors that influence China's two primary benchmark interest rates using quarterly frequency data from 1987 to 2013 and a variety of constrained ordered probit models and suggested that output gaps and the exchange rate have little impact on the PBC's policy choices, which are better understood as responses to changes in inflation and money growth. Aquilina et al. [11] discovered the enhanced liquidity effects in the USD swaps market after switching to the controlled ICE Swap Rate and so that regulations that enhance the benchmarking process and oversight can have a favorable effect on markets.

In this paper, we construct a dynamic model of a banking loan that takes the loan benchmark interest rate into account while calculating loan interest. Based on the sign of the loan's marginal profit, the gradient adjustment process upon which the model is built determines how much money will be lent in the future. This model is introduced by [18] which studying the role of capital regulations in banking loan dynamics. Several researchers have been used the model to study many aspects and regulations in the banking industry, such as the bank's operating costs, micro- and macro-prudential instruments, dividend payments, and deposit insurance premium [2–4, 9, 10, 12, 15, 16, 19]. This study uses the bifurcation theory to investigate how the benchmark interest rate affects loan dynamics. The results of the analysis demonstrate that the stability of the equilibrium loan is sensitive to the benchmark interest rate.

2 Model

Suppose a bank's balance sheet consists of: loan (L), equity (E), and deposit (D). The central bank's capital rule will establish lower ceilings for the bank's equity.

The banking data reveals that the equity to loan ratio can be assumed to remain constant in practice [9]. So, we can write: $\frac{E}{L} = \kappa$, for some $0 < \kappa < 1$. Suppose that the deposit serves as the balancing variable. Then, we have

$$D = L - E = (1 - \kappa)L.$$

Assume that the model is considered in discrete time $t = 0, 1, 2, 3, \ldots$. The model employs a gradient adjustment process to depict the loan dynamics as used in [14, 18]. The loan model is given below

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

where α_L is called the speed of adjustment parameter, $\alpha_L > 0$.

The bank's profit (π) is calculated by subtracting the cost of deposits ($r_D D$), equity ($r_E E$), and operational (C) from the loan interest ($r_L L$). According to the Monti-Klein model's underlying assumptions, the interest rates for loans and deposits are determined by [23, 24]

$$r_L = a_0 + a_1 - b_L L \tag{2}$$

and $r_D = a_D + b_D D$, where $a_0, a_1, b_L, a_D, b_D > 0$. In Eq. (2), a_0 is loan benchmark interest rate and a_1 is difference of benchmark and individual bank interest rate. The central bank rate parameter a_0 will be analyzed in this paper as the main topic. The equity expense r_E is taken to be a constant. The costs of loans and deposits are incorporated into the bank's operational expenses: $C = c_D D + c_L L$, where $0 < c_D, c_L < 1$.

The profit at time t is calculated as

$$\begin{aligned} \pi_t &= r_L L_t - r_D D_t - r_E E_t - C_t \\ &= (a_0 + a_1 - [r_E \kappa + c_L + (a_D + c_D)(1 - \kappa)])L_t - [b_L + b_D(1 - \kappa)^2]L_t^2. \end{aligned}$$

Then the loan's marginal profit is calculated

$$\frac{\partial \pi_t}{\partial L_t} = a_0 + a_1 - [r_E \kappa + c_L + (a_D + c_D)(1 - \kappa)] - 2[b_L + b_D(1 - \kappa)^2]L_t. \tag{3}$$

Subtituting (3) into (1) produces the dynamic model of banking loan as follows

$$L_{t+1} = L_t + \alpha_L L_t(a_0 + a_1 - [r_E \kappa + c_L + (a_D + c_D)(1 - \kappa)] - 2[b_L + b_D(1 - \kappa)^2]L_t). \tag{4}$$

2.1 Stability Analysis

The equilibrium of the loan in model (4) can be obtained by setting $L_{t+1} = L_t$. There are two equilibriums

$$L_1^* = 0 \quad \text{and} \quad L_2^* = \frac{a_0 + a_1 - [r_E \kappa + c_L + (a_D + c_D)(1 - \kappa)]}{2[b_L + b_D(1 - \kappa)^2]}.$$

In order to have economically meaning, the equilibrium L_2^* must be positive, or in other words

$$a_0 + a_1 > r_E\kappa + c_L + (a_D + c_D)(1-\kappa). \tag{5}$$

The model (4) might be rewritten as $L_{t+1} = f(L_t)$. The model is shown as a one-dimensional map. The equilibrium of the map is stable if $|f'(L^*)| < 1$ [1]. The formula for f's first derivative is

$$f'(L_t) = 1 + \alpha_L(a_0 + a_1 - [r_E\kappa + c_L + (a_D + c_D)(1-\kappa)]) - 4\alpha_L[b_L + b_D(1-\kappa)^2]L_t.$$

The stability of the equilibriums L_1^* and L_2^* is given by the following theorem.

Theorem 2.1. *The loan equilibrium $L^*_{(1)}$ is unstable. On the other hand, the loan equilibrium L_2^* is stable if $a_0 < \dfrac{2}{\alpha_L} + r_E\kappa + c_L + (a_D + c_D)(1-\kappa) - a_1$.*

Proof. Considering that

$$f'(L^*_{(1)}) = 1 + \alpha_L(a_0 + a_1 - [r_E\kappa + c_L + (a_D + c_D)(1-\kappa)]) > 1$$

consequently, L_1^* is unstable.
For the second equilibrium, we have

$$\begin{aligned} f'(L^*_{(2)}) &= 1 + \alpha_L(a_0 + a_1 - [r_E\kappa + c_L + (a_D + c_D)(1-\kappa)]) - \\ &\quad 2\alpha_L(a_0 + a_1 - [r_E\kappa + c_L + (a_D + c_D)(1-\kappa)]) \\ &= 1 - \alpha_L(a_0 + a_1 - [r_E\kappa + c_L + (a_D + c_D)(1-\kappa)]). \end{aligned} \tag{6}$$

It is clear that $f'(L^*_{(2)}) < 1$, because $\alpha_L(a_0 + a_1 - [r_E\kappa + c_L + (a_D + c_D)(1-\kappa)])$ is positive (the consequence of (5)) and one minus that is less than one. On the other hand, $f'(L^*_{(2)})$ will be greater than -1 if

$$a_0 < \frac{2}{\alpha_L} + [r_E\kappa + c_L + (a_D + c_D)(1-\kappa)] - a_1. \tag{7}$$

Thus, $|f'(L^*_{(2)})| < 1$ holds if the condition (7) holds. Therefore, $L^*_{(2)}$ is stable if the condition (7) is fulfilled.

□

2.2 Transcritical and Flip Bifurcations

We adhere to the Jury stability conditions for a one-dimensional map [20]. The equilibrium $L^*_{(2)}$ will experience transcritical bifurcation at $f'(L^*_{(2)}) = 1$. The equilibrium $L^*_{(2)}$ becomes unstable because of flip bifurcation when $f'(L^*_{(2)}) = -1$. The primary goal of the paper is to investigate the benchmark interest rate parameter a_0. Therefore, the value a_0 will act as the bifurcation parameter. Simple calculations can be used to arrive at the next theorem.

Theorem 2.2. *When $a_0 = a_0^T$, the loan equilibrium $L^*_{(2)}$ may become unstable by transcritical bifurcation, where*

$$a_0^T = r_E\kappa + c_L + (a_D + c_D)(1-\kappa) - a_1$$

and when $a_0 = a_0^F$, $L^*_{(2)}$ may become unstable due to flip bifurcation, where

$$a_0^F = \frac{2}{\alpha_L} + r_E\kappa + c_L + (a_D + c_D)(1-\kappa) - a_1.$$

Proof. We can immediately get the transcritical bifurcation value by solving the following equation for parameter a_0,

$$f'(L^*_{(2)}) = 1 - \alpha_L(a_0 + a_1 - [r_E\kappa + c_L + (a_D + c_D)(1-\kappa)]) = 1.$$

We obtain $a_0^T = r_E\kappa + c_L + (a_D + c_D)(1-\kappa) - a_1$. The flip bifurcation value is similarly determined by solving the following equation for parameter a_0,

$$f'(L^*_{(2)}) = 1 - \alpha_L(a_0 + a_1 - [r_E\kappa + c_L + (a_D + c_D)(1-\kappa)]) = -1.$$

The solution is $a_0^F = \dfrac{2}{\alpha_L} + r_E\kappa + c_L + (a_D + c_D)(1-\kappa) - a_1$. □

It is evident that $a_0^T < a_0^F$. The benchmark interest rate parameter must be between the transcritical and flip bifurcation levels for the loan equilibrium to stay stable. Regarding the transcritical and flip bifurcation values implied by the necessity of the adjustment speed parameter, Theorem 2 makes the following claim.

Theorem 2.3. *The transcritical bifurcation value a_0^T and the flip bifurcation value a_0^F will have economically meaning (their value must be between 0 and 1) if*

$$-1 + r_E\kappa + c_L + (a_D + c_D)(1-\kappa) < a_1 < r_E\kappa + c_L + (a_D + c_D)(1-\kappa)$$

and

$$\frac{2}{1 + a_1 - [r_E\kappa + c_L + (a_D + c_D)(1-\kappa)]} < \alpha_L < \frac{2}{a_1 - [r_E\kappa + c_L + (a_D + c_D)(1-\kappa)]}$$

respectively.

Proof. The first condition is immediately obtained by rearranging the following inequality

$$0 < r_E\kappa + c_L + (a_D + c_D)(1-\kappa) - a_1 < 1.$$

Meanwhile, the second condition is immediately obtained by rearranging the following inequality

$$0 < \frac{2}{\alpha_L} + r_E\kappa + c_L + (a_D + c_D)(1-\kappa) - a_1 < 1.$$

□

3 Numerical Results

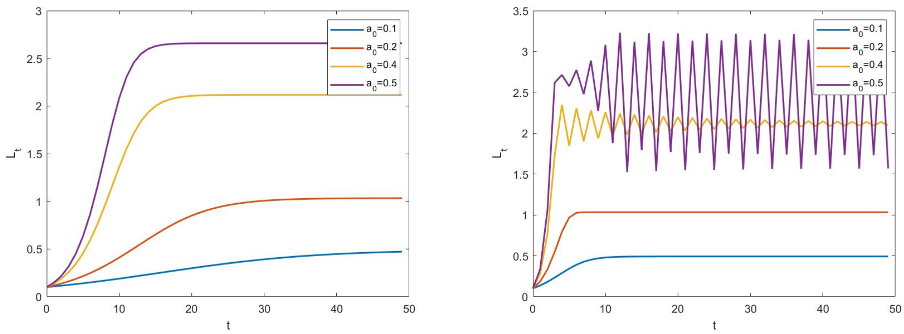
To illustrate and validate the findings from the preceding section, we run a number of numerical simulations. The values for the parameters indicated in Table 1 are used in the simulations. The settings of the parameters satisfy the equilibrium's positive condition $a_0+a_1 > r_E\kappa+c_L+(a_D+c_D)(1-\kappa)$ and conditions in Theorem 2.3 despite being solely determined for simulation reasons. The bifurcation values of benchmark interest rates are $a_0^T = 0.0092$ and $a_0^F = 0.2092$.

Table 1: Parameters value for the simulations

Parameter	**Value**	**Source**
a_0	0.1	Assumed
a_1	0.1	Assumed
b_L	0.05	[4]
a_D	0.01	[4]
b_D	0.05	[4]
r_E	0.05	[4]
κ	0.08	[4]
c_D	0.05	[4]
c_L	0.05	[4]
α_L	1, 5 and 10	Assumed
L_0	0.1 and 0.5	Assumed

All the following simulations are related to Eq. (4) and performed using Matlab software. First, we examine how the loan trajectory L_t changes over time in response to variations in the loan benchmark interest rate parameter a_0. Here, we plot the graph of L_t versus time t. Fig. 1a depicts convergent loan trajectory data. We may achieve this by using a tiny value of $\alpha_L = 1$. A lower number for a_0 results in a lower loan equilibrium. As the parameter a_0 increases in Fig. 1b, the trajectory of the loan varies when the value of α_L is relatively larger.

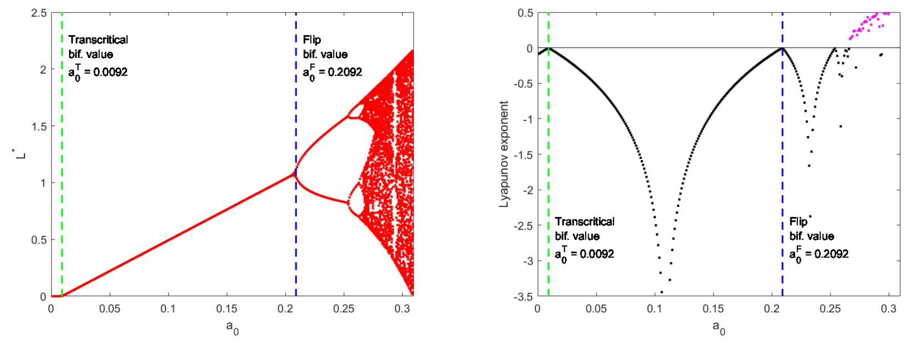
The dynamics of a map can be studied using bifurcation diagrams, which also offer numerous interpretations, such as whether or not the map is stable and when it might exhibit chaotic behavior. In Fig. 2a, we show a bifurcation diagram for the loan benchmark interest rate parameter a_0. Here, we plot L_t points versus each case of a_0 value, for time $t = 201, \ldots, 400$. The graph demonstrates that the loan equilibrium is zero when the benchmark interest rate parameter surpasses the transcritical bifurcation value, or $a_0 < a_0^T$. Whenever the benchmark interest rate parameter falls within the range of the transcritical and flip bifurcation values, or $a_0^T < a_0 < a_0^F$. When a_0 is very big, we get pandemonium because the loan equilibrium results in period-doubling (2-period, 4-period, 8-period, etc.) starting at $a_0 > a_0^F$. The curve of the Lyapunov exponent associated to Fig. 2a is shown



(a) (b)

Figure 1: Graphs of loan L_t versus time t for various values of the loan benchmark interest rate parameter a_0 for the case of (a) $\alpha_L = 1$ and (b) $\alpha_L = 5$.

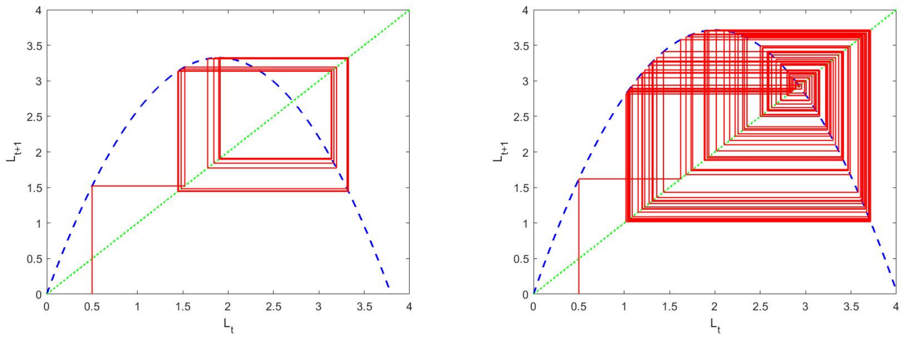
in Fig. 2b. the Lyapunov exponent is calculated by $l = \frac{1}{200}\sum_{t=201}^{400} \ln|f'(L_t)|$. We plot l versus each case of a_0 value. We exhibit the graph of the Lyapunov exponent with black dots if it does not exceed zero and purple dots otherwise. When the Lyapunov exponent is positive, the dynamics of loans becomes chaotic.



(a) (b)

Figure 2: (a) Bifurcation diagram of the loan benchmark interest rate parameter a_0 and (b) the respective Lyapunov exponent.

Another technique for examining the dynamics of the map's qualitative behavior is the cobweb diagram. The parameter used in this simulation is $a_0 = 0.51$, and $a_0 = 0.59$. Figs. 3a and 3b show the cobweb diagram for these scenarios. We plot L_t versus L_{t+1} starting from the initial value fro time $t = 0, \ldots, 100$. The black dashed line ($L_{t+1} = f(L_t)$) and the green dotted line ($L_{t+1} = L_t$) connect at the point where the red routes converge, showing that the paths are coming to an equilibrium. We show the dynamics of loans with 4-periodic cycles in direct trajectory and cobweb diagrams in Fig. 3a. The dynamics of loans in chaotic conditions are shown in the final figure, Fig. 6. We can see that the trajectory of the loan swings randomly indicating chaotic behaviour. The cobweb diagram yields comparable results as well.



(a) (b)

Figure 3: Cobweb diagram (L_t, L_{t+1}) when the loan benchmark interest rate parameter (a) $a_0 = 0.51$ and (b) $a_0 = 0.59$. The simulation uses $\alpha_L = 5$.

In the following simulation, chaotic loan behavior is examined using slightly different initial values. For the scenario $a_0 = 0.3$, Fig. 4 depicts an example of the chaotic behavior of the loan map. The graphic displays two graphs of the loan map with slightly different initial values. The black and red graphs' initial values are $L_0 = 0.5$ and $L_0 = 0.50001$, respectively. The black and red graphs in the illustration clearly resemble one another at first before diverging and forming different routes.

In the banking industry, there is no doubt that there are so many factors that affect the banking dynamics, and these factors create randomness in all banking aspects. Thus, now we assume that the loan benchmark interest rate a_0 is not constant, but stochastic. Suppose we change the parameter into $a_0 + \epsilon$, where ϵ is a white noise $N(0, \sigma^2)$. We simulate the banking loan L_t over time t in Fig 5 with $\sigma^2 = 0.01$ when the constant benchmark vary and the speed of adjustment α_L vary. From both simulations, it can be observed that the higher the constant benchmark or the speed of adjustment parameters produce bigger fluctuations in banking loan.

In Theorem 2.1, it is stated that the loan equilibrium is stable if $a_0 < \frac{2}{\alpha_L} + [r_E\kappa + c_L + (a_D + c_D)(1-\kappa)] - a_1$. Define a function of parameters, $S := \frac{a_0}{\frac{2}{\alpha_L} + [r_E\kappa + c_L + (a_D + c_D)(1-\kappa)] - a_1}$. Hence, the stability condition in Theorem 2.1 can be changed into $S < 1$. Now, we want to observe how the changes in parameters' value affect the stability of banking loan equilibrium, by observing the contour plot of the function S as a function of the loan benchmark interest rate parameter a_0 and other parameters. The simulation is given in Fig. 6. All the figures show that

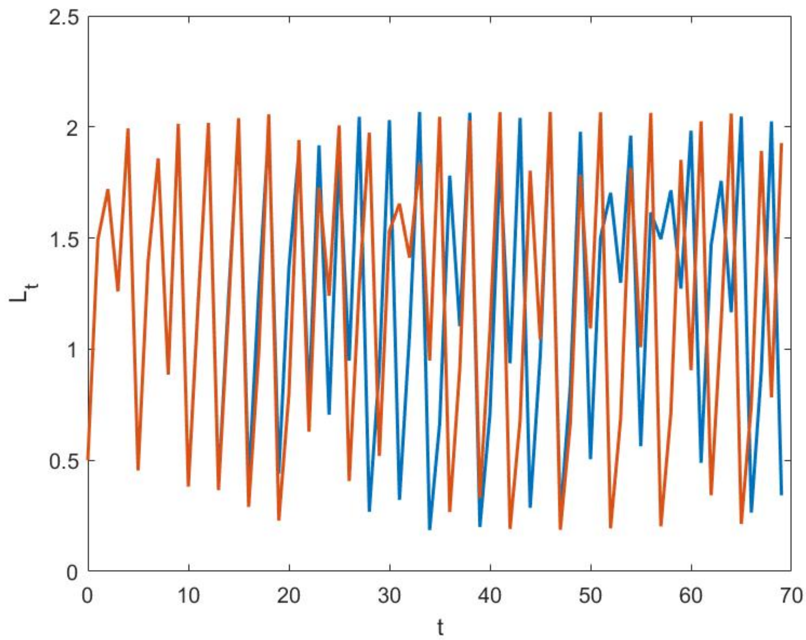
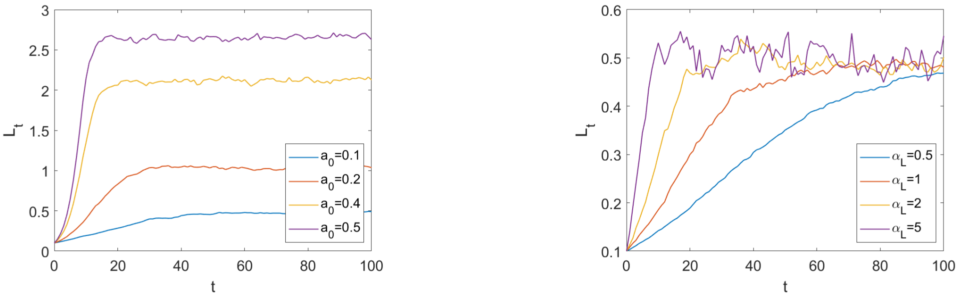


Figure 4: Sensitivity dependence of the chaotic loan dynamics on the initial condition for the loan benchmark interest rate parameter $a_0 = 0.3$. The simulation uses $\alpha_L = 10$

higher a_0 can cause unstable banking loan. For the case of parameters α_L, a_1, and κ, it can be observed that the loan can be unstable if their values becoming higher. On the other hand, the banking loan may be unstable if the parameters a_D, r_E, c_D, and c_L having smaller value.

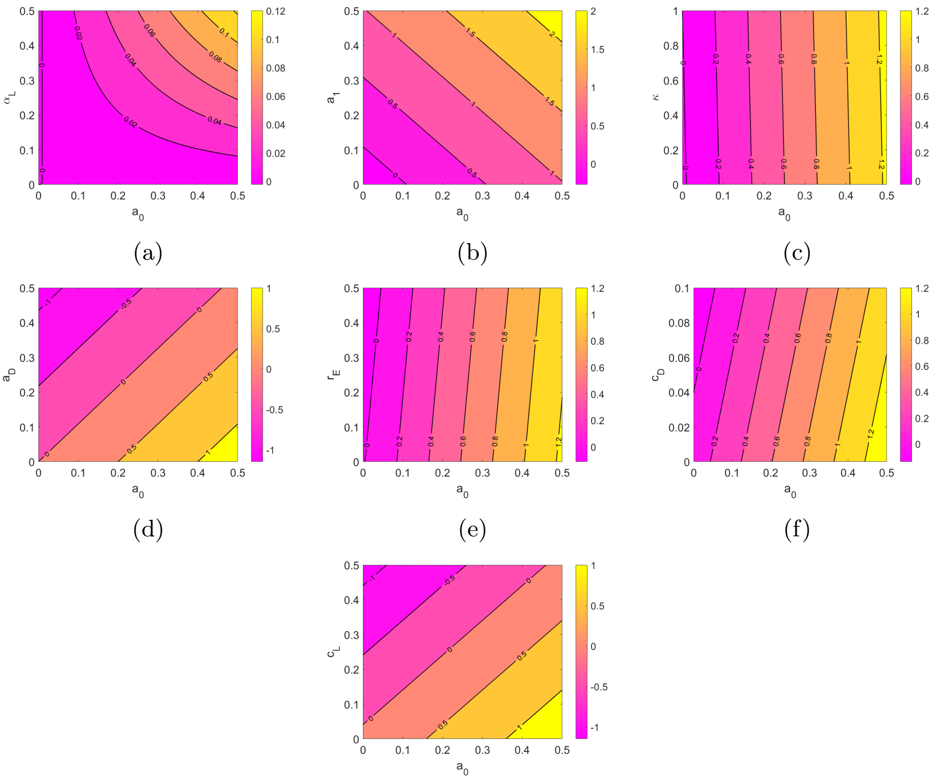
4 Conclusions

The loan benchmark interest rate is regulated by the central bank and it influences banks depend on it to determine their loan interest rate. The benchmark interest rate makes the size of the loan must be managed effectively and efficiently. In this study, a similar issue is impartially assessed to determine how it impacts the dynamics of loans. Lower benchmark interest rate result in lower loan equilibrium. The results of this study show that the benchmark interest rate shouldn't be too high or too low. When it is too high, loans destabilize and cause havoc. In the meantime, a loan with an abnormally low benchmark interest rate might inevitably default. The simulation of introduction of stochastic term in the benchmark interest rate suggests that the higher the benchmark or the speed of adjustment can cause



(a) (b)

Figure 5: Plot of banking loan when there is a randomness in the loan benchmark interest rate parameter a_0, when (a) the constant benchmark vary and (b) the speed of adjustment vary.



(a) (b) (c)

(d) (e) (f)

(g)

Figure 6: Contour plof of S as a function of two parameters: the loan benchmark interest rate a_0 and other parameters.

the banking loan having high volatility. The sensitivity analysis shows that the control of banking loan stability can be done by combining the benchmark interest rate with other parameters, that they must be set at certain conditions to guarantee a stable loan.

In this work, a single bank with a straightforward balance sheet structure is modeled relatively simply. The model can be generated into a more general model with more balance sheet components in order to handle specific banking policies, such as macroprudential policy, which focuses on limiting the growth of banking loans [8, 21], or it may be employed to banking data as well [5–7].

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