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Paper:

Agent-Based Simulation of Financial Institution Investment Strategy Under Easing Monetary Policy for Operative Collapses

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Europe and Japan have both adopted negative interest rate policies as part of their monetary easing measures. However, despite the benefits that are claimed to be associated with increased lending demand, significant concerns exist regarding an increased burden on private financial institutions as a result of the application to their excess reserves. In this paper, we focus on the risks associated with increased investment of surplus funds for the operation of financial institutions. We propose an agent-based model for interlocking specific bankruptcy based on changes in financial situations as a result of market price fluctuations involving assets held by financial institutions. To extend the proposed model to handle macro market shocks, we describe decision making regarding funds that are surplus to the operation of financial institutions. Additionally, we analyze the impact of price declines involving marketable assets on financial systems.

Keywords: systemic risk, negative interest rate policy, agent-based model, asset liability management

1. Introduction

Europe and Japan have both adopted negative interest rate policies as part of their monetary easing measures. However, despite the benefits that are claimed to be associated with increased lending demand as a result of decreased interest rates, private financial institutions face an increased burden as a result of the application of negative interest rates to their excess reserves. In Japan, from the viewpoint of the operation of financial institutions, any attempts to offset the expected decreased returns on domestic assets make a certain degree of risk taking inevitable [1]. Therefore, high-risk investment in risky assets and high-risk lending activities may increase.

We analyze the proactive financing behavior of financial institutions that endogenously expands the deterioration of the financial conditions of financial institutions as a result of price fluctuations in asset markets causing interlocking specific failure. By focusing on the asset liability management of financial institutions (Section 2.2), we propose an agent-based model that features the endogenous mechanisms of systemic risk.

In this study, we focused on the increased risk associated with the investment of surplus funds by financial institutions. Therefore, we extended our earlier model to help financial institutions make better decisions regarding the investment of their surplus funds. In the event of price declines in the asset market, by focusing on how they affect financial systems, we perform analysis of the increase or decrease in operative bankruptcy.

2. Related Work

2.1. Theoretical and Empirical Research Since the Global Financial Crisis

At the time of the global financial crisis, the deterioration of the market environment and capital positions impacting the creditworthiness of individual financial institutions caused procurement to become more difficult and multiple financial institutions manifested liquidity risks [2]. This issue negatively affected the cash-flow behavior of financial institutions. Regarding the mechanism of systemic risk, not only can a default affect other links in a common chain representing lending relationships, but there is also discussion regarding decision making related to changes in portfolios of marketable assets [3]. Such discussions focus not only on discrete shocks caused by the bankruptcy of general borrowers, but also on the effects of macro shocks caused by market price fluctuations involving assets held by financial institutions, resulting in chain collapse.

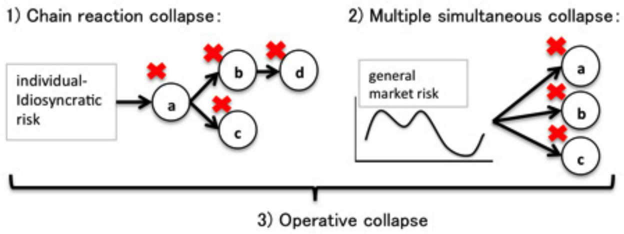


Fig. 1. Characteristics of bankruptcies. In particular, we consider multiple simultaneous collapses caused by the deterioration of the financial situations of individual financial institutions caused by price fluctuations in market holdings of assets.

2.2. Research on Financial Contagion

Theoretical and empirical studies on financial crisis propagation and infection include [4–6]. Studies focusing on banking and financial networks as complex networks include [7–11]. Additionally, [12–14] expanded the use of agent-based models. The following studies analyzed bank collapse propagation through the interbank (I/B) network and the general borrowers with which banks have lending relationships: [10, 11, 13, 14].

Collapse is often treated as inevitable. It is generally assumed that a shock is caused by individual and idiosyncratic risk factors. Some studies have also discussed exiting from the I/B market as a result of public sector funding [14] and clearing by the central bank following bankruptcy [13]. However, these studies did not directly consider the problem of the central bank assuming the functions of the financial intermediation market.

3. Definitions

3.1. Characteristics of Bankruptcies

The propagation of the collapse that initiated the recent financial shock as a result of individual idiosyncratic risk factors was investigated in prior research (discussed in Section 2.2) and is referred to as "chain reaction collapse." However, the macro collapse caused by the shock arising from general market risk factors is referred to in Section 2.1 as "multiple simultaneous collapse." This paper focuses on both forms of "operative collapse" (see **Fig. 1**).

3.2. Asset Liability Management

Asset liability management in which financial institutions attempt to maximize earnings refers to properly controlling the various risks associated with financial transactions. The three main types of risk are credit risk, market risk, and liquidity risk. The first two are caused by investment behaviors and the third is caused by cashflow behavior.

3.2.1. Investment and Lending Behavior

Financial institutions engage in both direct lending and general lending as part of their financial intermediary functions. Additionally, when a bank or securities company owns the marketable assets of entities involved in proprietary trading for profit, these assets constitute a balance sheet. Although each asset is exposed to both credit risk and market risk, in this paper, we refer to the classification of risk as general market risk and individual risk [15, 16]. In the proposed model, we classify subjects of investment as "marketable assets" and "non-marketable assets." Notably, regarding the investment behavior discussed in this section, the handling of the intrinsic operation of marketable assets and investments in marketable assets in surplus operating behavior is later described and distinguished.

3.2.2. Financing Behavior (Normal Situation)

Capital surpluses and shortages (funding gaps) arise from the day-to-day investment behavior and financing situations of financial institutions. The short-term money market provides a means to adjust these funding gaps. This is particularly important in the case of Japan, especially in its call market.

Typical financial surplus institutions include pension funds and life insurance providers, while financial shortage institutions include mega-banks and securities companies. On average, financial surplus institutions have higher total balances than financial shortage institutions [17]. The flow of funds in the normal money market can be schematically represented in several forms [18].

The proposed model does not include money market dealers or trading rates in contract decisions, but instead assumes that lenders only consider the credit situation and their own tradable funds.

3.2.3. Financing Behavior (Monetary Easing Situation)

Following the global financial crisis and in the current environment of monetary easing, the operational procurement of funds is increasingly occurring through the balance sheet of the central bank. Financial institutions and central banks are connected through their balance sheets by 1) the supply of funds and 2) the current account. Given the combination of an accommodative monetary environment and financial crisis, the supply of funds from the central bank to commercial banks and from commercial banks to other financial institutions is expanded and the central bank adjusts the capital surplus/shortage [18] (**Fig. 2**). This event can be interpreted as one in which the central bank performs the financial intermediation function of the call market.

3.2.4. Surplus Operating Behavior

In the proposed model, if surplus funds exist following the implementation of the investment and financing behavior mentioned above, an investment decision must be made between 1) a central bank current account or 2) marketable assets.

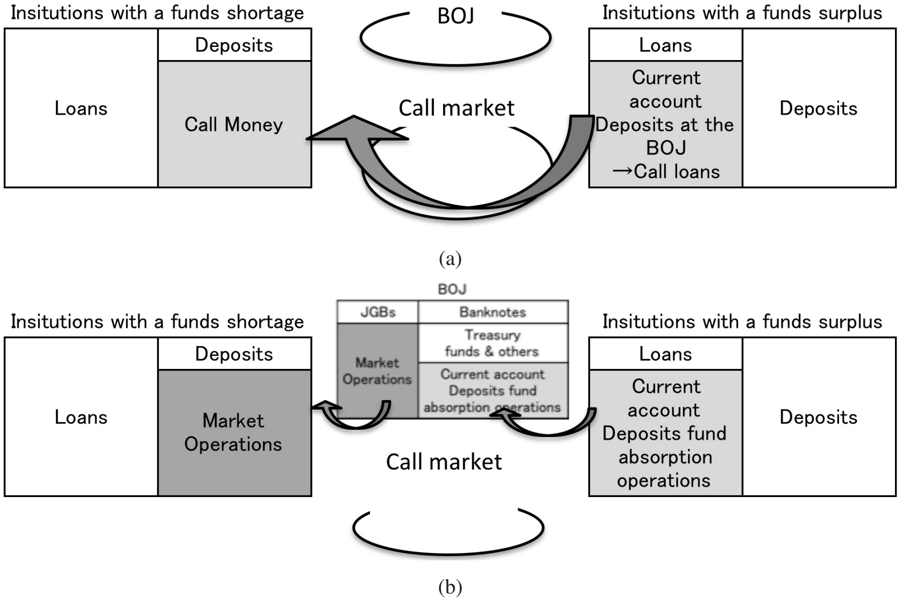


Fig. 2. (a) Normal financing behavior in the money market: institutions with a surplus of funds release call loans to those with a shortage of funds [18]. (b) Recent financing behavior in the money market: the central bank meets an increasing proportion of the funding requirements of institutions with a shortage of funds [18].

3.3. Management Constraints

To prevent a recurrent financial crisis, various measures are being implemented to strengthen the soundness of banks (Basel III) and achieve financial regulatory reform in diverse fields, including reforms to systemically important financial institutions. In the proposed model, we adopt the capital adequacy ratio (soundness indicator) and value at risk (VaR) (risk indicator) as management constraints. The actions of financial institutions under these constraints are discussed in Section 4.6.2.

3.4. Bankruptcy Mechanisms

In the proposed model, the bankruptcy factors affecting financial institutions are as follows: 1) excessive debt, 2) decrease in capital adequacy ratio to below a certain value, and 3) lack of post-funding funds to continue procurement. The first factor refers to general loans and I/B loans that are written off because they cannot be absorbed by a company's capital balance. Therefore, this factor resembles that utilized in the model of May and Arinaminpathy (hereafter referred to as the M-A model) [10]. Considering the case of Japan as an example, the second factor is a capital adequacy ratio that is consistent with uniform international standards, meaning a value exceeding 8% [19]. The third factor describes a situation in which a company cannot resolve its lack of funds in the short-term money market (i.e., the company faces financial collapse). **Fig. 3** compares these bankruptcy factors with those cited in previous studies.

4. Model

4.1. Outline

Agents are financial institutions with balance sheets and financial indicators (e.g., capital adequacy ratio). The market value of securities fluctuates in response to price fluctuations of marketable assets. Networks are either 1) lending networks to businesses or 2) I/B networks for short-term investment and funding involving financial institutions. Additionally, each financial institution is directly connected to the central bank and can access central bank depositing and lending facilities. Furthermore, each financial institution engages in a) investment behavior (increasing or decreasing securities and/or lending to business corporations on its balance sheet) and b) financing behavior (filling any gaps between balance sheet debits and credits).

We extended the M-A model to analyze certain aspects of the bankruptcy chain based on changes in the balance sheets of individual financial institutions [20–22].

The proposed model has the following characteristics. 1) Each financial institution has a simplified balance sheet and engages in short-term lending and borrowing through the I/B network. 2) The collapse of financial institutions is permitted to observe the impact of such collapses on the capital of other financial institutions with which the collapsed institution has lending relationships. 3) An institution suffers bankruptcy when its capital is insufficient to absorb a given financial shock. This feature is important for representing the chain of failure.

Additionally, our model incorporates:

1) Deterioration in the financial and credit situations of financial institutions based on fluctuations in the

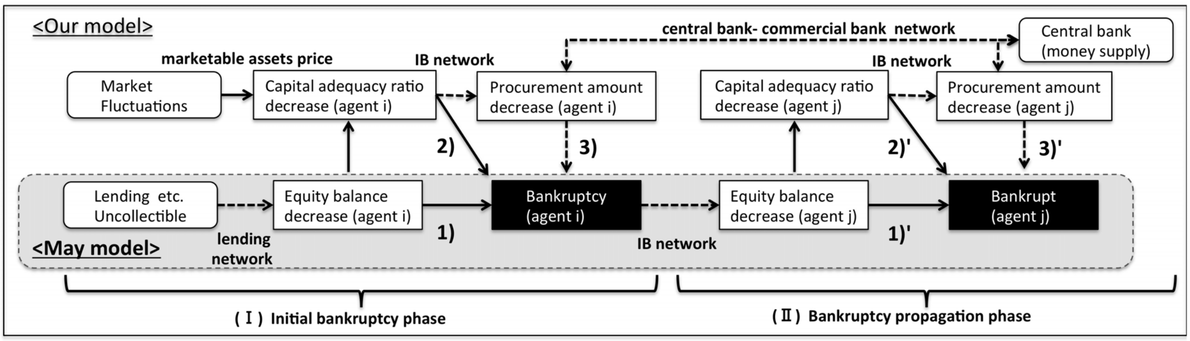


Fig. 3. Bankruptcy factors in the proposed model: 1) Decrease in equity balance, similar to the model of May and Arinaminpathy [10]. 2) Decrease in capital adequacy ratio. 3) Decrease in procurement volume by institutions with a shortage of funds.

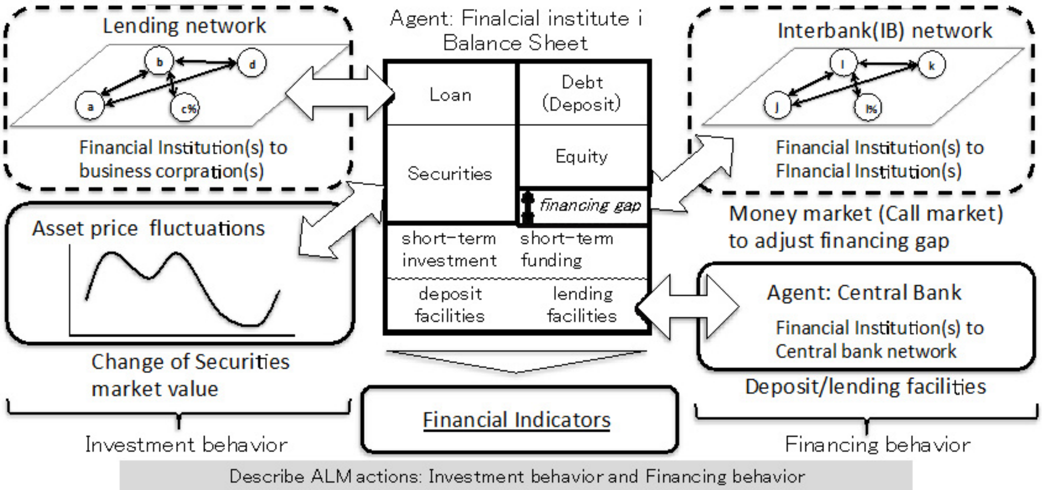


Fig. 4. Conceptual model: this model explicitly describes asset-liability management (ALM) actions, such as investment and financing activities. Funding changes and changes to the central bank's financial situation as a result of price fluctuations in the asset market represent the impact of ALM actions on operational collapse.

market prices of assets held (capital adequacy ratio).

2) Increases in cash-flow shortfall and liquidity risk as a result of deterioration in the financing environment in the I/B market.

3) Central bank funding to prevent bankruptcy (see **Fig. 4**).

Notably, because we examine the impact of surplus operating behavior and price fluctuations of market assets on financial conditions and the cash flow of financial institutions, we do not consider trading networks for non-marketable assets.

4.2. Agents

4.2.1. Financial Institutions

In the M-A model [10], each financial institution

$$a\_i (i = 1, \dots, N), A = \{a\_i | i = 1, \dots, N\}$$

has a simplified balance sheet that can be summarized as follows (see **Table 1**). Each balance sheet consists

Table 1. Balance sheet items for commercial financial institutions.

Debit	Credit
cash CA non-marketable asset nonMA	debt D
marketable asset MA^{bookvalue}	equity E
deposit facilities DF	lending facilities LF
short-term investment SI	short-term financeing SF

of 1) cash CA_i, 2) marketable assets $MA_i^{bookvalue}$, 3) non-marketable assets $nonMA_i$, 4) debt D_i, 5) equity E_i, 6) deposit facilities DF_i, 7) lending facilities LF_i, 8) short-term investment SI_i, and 9) short-term financing SF_i.

The financing gaps and funding surplus/shortage institutions are then defined as follows:

$$Gap_i = D_i + E_i - CA_i - nonMA_i - MA_i^{bookvalue}$$

$$C^{surplus} = \{a\_i | Gap_i >= 0\}$$

$$C^{shortage} = \{a\_i | Gap_i < 0\}.$$

Table 2. Balance sheet items for the central bank.

Debit	Credit
Lending facilities LF^{CB} Surplus SU^{CB}	Deposit facilities DF^{CB}

Note that the status of each financial institution remains unchanged.

We also define the unrealized profit or loss (UP_i), capital adequacy ratio (CAR_i), income profit (IP_i), and return on equity (ROE_i) as follows:

$$UP_i = MA_i^{tmarketvalue} - MA_i^{bookvalue}$$

$$CAR_i = \frac{E_i + UP_i + \Sigma CP_i}{nonMA_i + MA_i^{bookvalue}}$$

$$IP_i = \beta^* MA_i^{bookvalue} + \gamma^* nonMA_i$$

$$ROE_i = \frac{IP_i}{E_i}$$

where β and γ denote the rates of return for marketable and non-marketable assets, respectively. $MA_i^{tmarketvalue} = (MA_i^{bookvalue}/P_0) * P_t$, where P_t is the market price of the marketable assets at step t. CP_i denotes the realized gains and losses as a result of operating surpluses, as defined in Section 4.6.5.

Additionally, financial institutions face the requirement that they maintain a minimum capital adequacy ratio ($CAR\text{-}demand_i$). In a case where institutions facing a shortage of capital have ordered that funds be supplied to institutions with a capital surplus, *CAR-demand* is the lowest capital adequacy ratio required by the institutions facing a capital shortage.

4.2.2. Central Bank

The central bank CB also has a simplified balance sheet (see **Table 2**). The central bank's balance sheet consists of lending facilities LF^{CB}, deposit facilities DF^{CB}, and surpluses SU^{CB}.

The central bank's deposits are r_{DF}% of the fund surplus of stacked surplus institutions (stack ratio). r_{DF} is the ratio representing the amount of surplus that surplus institutions deposit from their own fund to the central bank. Additionally, in the supply of funds for community financial institutions, the central bank's deposits serve as an upper limit for the size of the funding gap in shortage institutions as follows:

$$DF^{CB} = \sum_j DF_j = \sum_j ceil(Gap_j * r\_{DF})$$

$$LF_k = floor\left(DF^{CB} * \frac{Gap_k}{\sum_k Gap_k}\right)$$

$$LF^{CB} = \sum_k LF_k$$

$$SU^{CB} = DF^{CB} - LF^{CB}$$

$$Gap'_i = Gap_i + LF_i + SF_i - DF_i - SI_i.$$

Then, $a\_j \in C^{surplus}$, $a\_k \in C^{shortage}$, $a\_i \in A$, and $ceil(x) = \text{argmin}\{x <= n | n \in Z\}$, $floor(x) = \text{argmax}\{x >= n | n \in Z\}$.

4.3. Networks

4.3.1. I/B Network

Financial institution a_i engages in short-term investment and funding transactions with other financial institutions

$$W_i^{Interbank} = \{a\_p | m\_{ip} = 1\}$$

and attempts to eliminate the funding gaps between itself and connected institutions. $M = (m\_{ip})$ is the adjacency matrix of the I/B network and $a\_p \in A$.

4.3.2. Central Bank – Financial Institutions Network

Financial institution a_i has a one-to-one network with the central bank.

4.4. Financing Behavior

4.4.1. Financing of Shortage Institutions by Surplus Institutions

(Step 1) Shortage institution a_k issues financing orders to surplus institution a_j ($amount_k^j > 0$) as follows:

$$Order(k, j, amount_k^j).$$

Additionally, a_k denotes all surplus institutions that lend to the I/B network and follow the requirement to evenly split the value of their own financing gaps.

Here, $(a\_k, a\_j) \in C^{surplus} \times C^{shortage}$, δ is the minimum order size $\in Z$, and $amount_k^j = \max(ceil(Gap'_k / |(C^{surplus} \cap W_k^{Interbank})|), \quad \delta) \in Z$, where Z is the set of integers.

(Step 2) a_j checks the financial conditions and amount of self-funding available for a_k to perform contract judgment.

- Contractual conditions:

  $CAR_k >= CAR\text{-}demand_j$ and

  $amount_k^j =< Gap'_j - \Sigma amount^{j\,other\,implemented-orders}$

- Non-contractual conditions:

  Otherwise,

  where $amount^{j\,other\,implemented-orders}$ are the transactions that a_j has already committed.

(Step 1') If there is no contract, a_k is to either change the order destination to another surplus institution a_q or reduce the order amount. It is possible to perform one or both of these actions.

$$Order(k, j, amount_k^j) \to Order'(k, q, amount'^q_k)$$

$$Order(k, j, amount_k^j) \to Order'(k, j, amount'^j_k)$$

$$Order(k, j, amount_k^j) \rightarrow Order'(k, q, amount'^q_k)$$

Then, $a\_q \in C^{surplus} \cap W_k^{Interbank}$, $amount_k' = floor(amount_k/2) >= \delta$.

(Step 3) If a_k cannot meet $Gap_k' >= 0$, a_k goes bankrupt.

4.4.2. Other Short-Term Investment and Funding

Assuming cross-trades are carried out (both institutions built transactions) [17], we consider the following short-term funding or investment transactions between financial institutions. A certain percentage of the balance sheet amount becomes the upper limit.

- Between shortage–shortage and surplus–surplus institutions:

a_i has an upper limit of l transactions with a_s of the same status and generates the following order:

$$Order(i, s, amount_i^s) \text{ or } Order(s, i, amount_s^i).$$

- Between surplus–shortage institutions:

a_j has an upper limit of l transactions with a_k of the same status and generates the following order:

$$Order(j, k, amount_j^k).$$

Then,
$amount_j = ceil((CA_j + MA_j^{bookvalue} + nonMA_j)^* \varepsilon)$, $l = floor((CA_j + MA_j^{bookvalue} + nonMA_j)^* \zeta / amount_j)$.

4.5. Investment Behavior

This study examined the issue of high-risk investment of surplus funds and its effects on the operation of financial institutions, which is an issue that is not handled by intrinsic investment behavior. In other words, without decision making based on the increase or decrease of assets, in this section, the balance of marketable assets is assumed to be constant.

4.6. Surplus Operating Behavior

4.6.1. Outline

SU_j represents the surplus funds of surplus institutions $a\_j \in C^{surplus}$ that have positive financing gaps based on the financing behavior described in Section 4.4. In accordance with the VaR constraints and asset preferences at each step, a_j makes investment decisions regarding marketable assets or central bank deposits. In the proposed model, while following absolute VaR constraints, decisions are made regarding the purchase of marketable assets after considering preferences.

4.6.2. Formulation of Management Contract and Market Outlook

Various constraints and market outlooks are defined in **Table 3**.

$$VaR_i = MA_i^{bookvalue} * \sqrt{n}\_{days} * (r\_{avg} - \eta * \sigma\_m)$$

r_{avg} and σ_m are calculated from the daily return of P_t (sample period: m days). $\sqrt{n}\_{days}$ is the time scaling of risk based on the square root of the time rule. η is a confidence level scaling factor. r_{avg} is the average return on the marketable asset price. σ_m is the standard deviation of return on the marketable asset price. r_{exp} is the expected return on the marketable asset price. r_{depo} is the return on the central bank deposit.

Table 3. Management contracts and market outlook.

Contracts	Formulation
a) VaR	$VaR_i < E_i * (MA_i/(MA_i + nonMA_i))$
b) Marketable Asset Preference	$f_{M\text{-}A} = r_{exp} - \lambda_i * \sigma_m$
c) Deposit Preference	$f_{depo} = r_{depo}$

4.6.3. Investment Decision Making

Under the above constraints, a financial institution decides to buy, sell, or hold market assets as follows:

$$\text{Buy}: (f_{M-A} \geq f_{depo}), \text{ Sell}: (f_{M-A} < f_{depo}).$$

4.6.4. Decisions Regarding Buying and Selling Amounts

If buying or selling was selected in the previous step, the buying or selling amounts are defined as follows:

Buying Amount: The financial institution determines the buying amount as follows:

$$buyamount_j^t = \min(buyable_j^t, SU_j^t * \theta)$$

Then, buyable is calculated based on the upper limit of the VaR constraint. θ is a parameter that determines the upper limit of the buying amount of marketable assets.

4.6.5. Occurrence of Realized Gains and Losses

Market assets that exist as a result of an operating surplus are cleared in step-by-step fashion and it is assumed that realized gains and losses may occur at each step. The realized gains and losses at step t (CP_i^t), as well as the total profit and loss (TP_j) are defined as follows:

$$CP_j^t = buyamount_j^{t-1} * \left(\frac{P\_{t-1}}{P\_{t-2}} - 1\right) (t \geq 2).$$

$$TP_j = UP_j + IP_j + \sum_t CP_j^t$$

4.7. The Effects of Bankruptcy

4.7.1. Individual Bankruptcy

If the capital adequacy ratio is less than or equal to the threshold value, or if the funding gap is not filled, then financial institution a_i will experience bankruptcy as follows:

$$CAR_i < \alpha \text{ or } Gap_i' < 0.$$

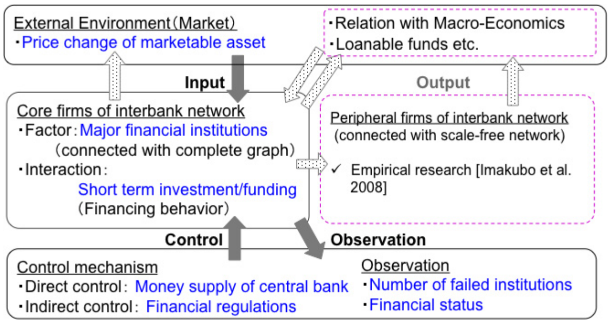


Fig. 5. Limitations of the proposed model. Our model is able to describe the concepts in solid lines/black arrowed lines and not able to describe those in broken lines/white arrowed lines.

Our model is not able to describe (in broken lines/white arrowed lines):

d) The presence of financial institutions in the periphery of the I/B network.

e) The influence of the behavior of financial institutions on price fluctuation of marketable assets.

f) The mutual influence that a financial institution in the I/B network has on the real economy.

Additionally, our model makes the following simplifications:

g) Limiting marketable assets to one.

h) Disregarding the loan behavior of financial institutions.

4.7.2. Chain Reaction Collapse

If financial institution a_i experiences bankruptcy, the financial institutions a_y that are involved in short-term operations with the first financial institution are regarded as unexposed with regard to those investments and it is assumed that the capital cancels out.

$$E'_y = E_y - SI_y^i$$

If one of the following conditions is satisfied, financial institution a_y also suffers bankruptcy and a chain reaction collapse occurs:

$$E'_y < 0 \text{ or } Gap'_y < 0 \text{ or } CAR_y < \alpha$$

4.8. Evaluation

In this paper, we examine a case where the current deposit interest rate r_{depo} is changed to assess the impact of a change in the surplus operating behavior of each financial institution on the overall financial system. Specifically, the number of surviving financial institutions (or number of failed financial institutions) is utilized as a macro indicator in the model.

4.9. Limitations of the Proposed Model

The limitations of the proposed model are presented in **Fig. 5**.

Our model is able to describe (in solid lines/black arrowed lines):

a) Changes in the financial situations of major financial institutions in the I/B network caused by price changes of marketable assets in the external environment.

b) The financing behavior, investment behavior, and surplus operating behavior of financial institutions under financial regulations and management contracts.

c) The financial situation of each financial institution and number of failed financial institutions.

5. Analysis of Model Behavior

Our computational experiments analyzed the applications of surplus funds in accordance with organization preferences and operational constraints. We observed the dynamics regarding the impact on the bankruptcy chain by changing r_{depo}.

5.1. Price Time Series of Marketable Assets

The price of risky assets is assumed to follow the discretized stochastic differential equation presented below [23]:

$$P_{t,j} = P_{t-1,j} + r_f P_{t-1,j}\Delta t + \sigma P_{t-1,j}\tilde{\varepsilon}\sqrt{\Delta t}$$

where t is the time step $(t = -m+1, \ldots, 0, 1, \ldots, T)$, j is the trail number, $P_{t,j}$ is the price of a marketable asset (j times, step t) $(P_0 = 100)$, r_f is the risk-free rate [%], σ is volatility [%], and $\tilde{\varepsilon} \sim N(0,1)$. In this simulation, we set 1 step $=$ 1 day $= 1/250$ year and $\Delta t = 1/250$, where $T = 125$ (assuming six months is the budget-closing period for a bank account). Additionally, considering long-term government bond yield levels and stock markets in each country, $r_f = 2\%$ and $\sigma = 25\%$. A total of 100,000 sample paths were generated and marketable asset prices in the final step were utilized to track a time series with slight increase (broken line, **Fig. 6**) and the lowest time series (solid line, **Fig. 6**).

5.2. Common Settings

Table 4 lists the parameters utilized in our experiments. There are 20 financial institutions (#1–#20, including 10 surplus and 10 shortage institutions) and the I/B network is a complete graph. In terms of the financing gap, because surplus institution's total amount outnumbered shortage institution's one, surplus institutions were subjected to the following adjustment:

$$\text{(Financing gap adjustment)} \\ = \frac{\sum (MA_i^{bookvalue} + nonMA_i) * \kappa}{\#C^{surplus}}.$$

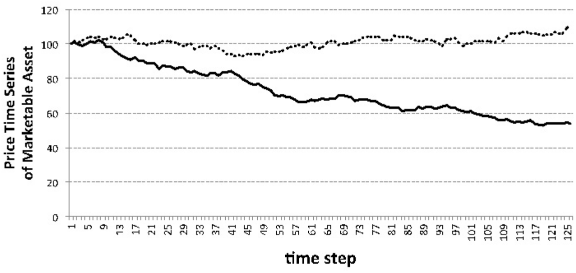


Fig. 6. Price time series of marketable assets employed in our simulation. A total of 100,000 trials were performed and we tracked a price time series with slight increase (broken line) and the lowest time series (solid line).

Table 4. Parameter settings utilized in this simulation. There were three mains reasons for these parameter settings: (A) Research purpose, (B) Measured value, (C) Preliminary experiment.

Parameters	Value	Classification
Number of institutions N	20	(A)
Interbank network $W^{Interbank}$	Complete graph	(A)
Cash CA	10–25, uniform distribution	(B)
Non-marketable asset nonMA	100, constant	(B)
Marketable asset MA	20–50, uniform distribution	(B)
Financing gap Gap	BS amount*5%<=|Gap| <= BS amount*10%	(B)
Capital adequacy ratio CAR	12%–22%, uniform distribution	(B)
CAR-demand CAR-demand	0%–3%, uniform distribution	(C)
Risk aversion λ	0.0–1.0, uniform distribution	(C)
Budget target y	1.5–2.0, uniform distribution	(C)
Stack ratio r_{DF}	30%	(C)

Additionally, for balance sheet items outside the table, we set the capital based on a given capital adequacy ratio. After accounting for the financing gap, liabilities were determined via back calculation such that credits and debits matched. We then set the short-term investment and funding parameters as follows: α: 0%, β: 1.2%, γ: 1.0%, δ: 1, ε: 1%, ζ: 5%, η: 2.33, θ: 10%, ι: 10%, κ: 10%, n_{days}: 10, m_{days}: 16.

There were three main reasons for these parameter settings:

(A) Settings according to research purpose:

The settings correspond to the number of financial institutions N and I/B network shape $W^{interbank}$.

(B) Settings based on measured values:

The settings correspond to the financing gap Gap set by the average balance of lenders and borrowers in the call market [17], capital adequacy ratio CAR etc. These figures were mainly set for the Japanese market as an example.

(C) Settings based on preliminary experiments:

For parameters that are difficult to empirically validate, we verify the behavior of the model preliminarily in Section 5.3. While checking the sensitivity of the parameters, it was determined if the set value of a parameter deviated from the realistic range.

5.3. Experiments

5.3.1. Profit and Loss of Financial Institutions

First, as a preliminary experiment, we analyzed the profit and loss of financial institutions in a case where the price fluctuation of marketable assets slightly increases (**Fig. 6**, broken line) utilizing the parameter in **Table 4**. **Table 5** lists the average value and standard deviation of the total profit and loss of each financial institution when changing the current deposit rate. As the current account rate is lowered, the total profit and loss of each financial institution at the final time step increases. This matches the benefits envisaged by the easing monetary policy. Each financial institution has reasonable decisions to make to earn profits.

Table 5. Total profit and loss of financial institutions (above: average, below: s.d.). As the current account rate is lowered, the total profit and loss at the final time step increases.

$r_{\text{–}depo}$	Total Profit and Loss		
	Final Step	Max	Min
+1.0%	94.7	94.7	−21.9
	(3.45)	(3.45)	(1.93)
0.0%	105.4	105.4	−29.3
	(2.95)	(2.95)	(2.00)
−1.0%	108.6	108.6	−30.4
	(3.59)	(3.59)	(2.26)

(Above: average, below: s.d.)

5.3.2. Stability of the I/B Network

In the parameter set shown in **Table 4**, the current account interest rate is $r_{\text{–}depo}+$ 1.0%, while for all three test cases it is −1.0% for each of the 4,000 trials utilizing the lowest time series of marketable assets (**Fig. 6**, solid line).

Figure 7 presents a time series box-and-whisker plot showing the number of surviving financial institutions at each of the five steps. Lower account interest rates increase the variance in the number of surviving institutions. Overall, the number tends to be small. Specifically, the number of surviving institutions is 17 when $r_{\text{–}depo} = +1.0\%$, 13.7 when $r_{\text{–}depo} = 0.0\%$, and 12.3 when $r_{\text{–}depo} = -1.0\%$. Therefore, as the current account interest rate is lowered, risky assets that are more sensitive to market forces are more likely to be selected for investment. As a result, bankruptcies occur more often.

Figures 8(a) and **(b)** present the relative frequency distributions of the number of remaining banks at 100 steps and 125 steps, respectively.

At 100 steps, 20 companies remained in the cases where $r_{\text{–}depo} = 1.0\%$ and 19 companies remained in the cases where $r_{\text{–}depo} = 0.0\%$ or -1.0%. At 125 steps, 18 of the 20 companies remained in the case where $r_{\text{–}depo} = +1.0\%$ and 15 companies remained in the cases where $r_{\text{–}depo} = 0.0\%$ or -1.0%.

Additionally, if the interest rate was negative, the case where all institutions went bankrupt was observed and the distribution of the number of insolvent institutions was bimodal.

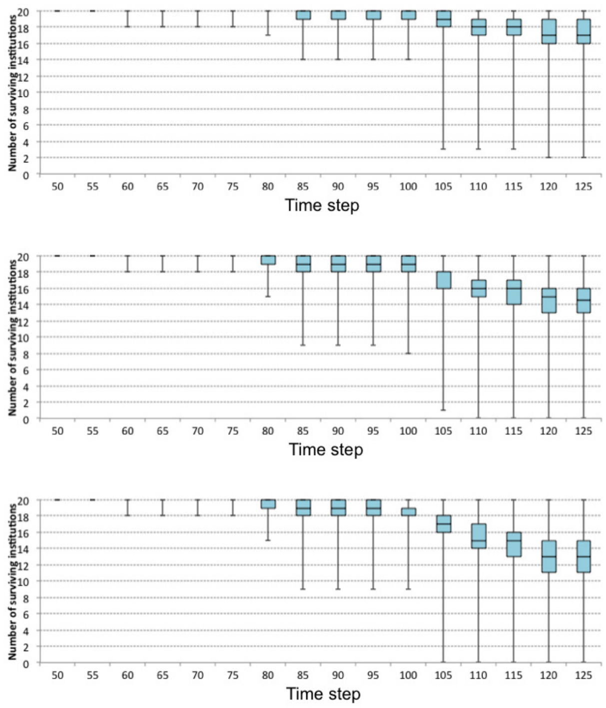
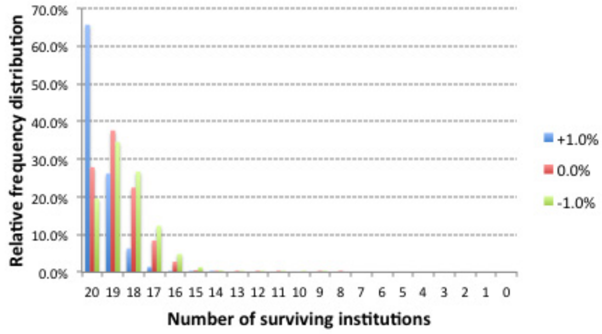
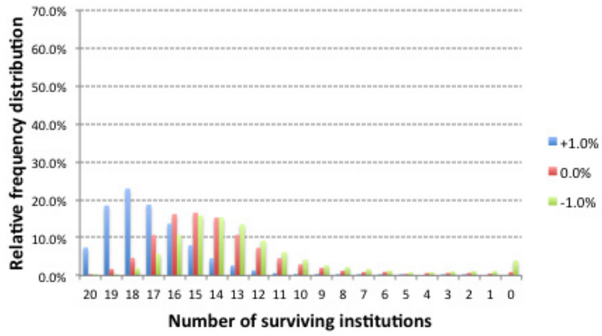


Fig. 7. Box-and-whisker plot of the number of financial institutions surviving at each of the five steps (top: deposit rate $= +1.0\%$, middle: deposit rate $= 0\%$, bottom: deposit rate $= -1.0\%$). As the current account interest rate is lowered, risky assets that are more sensitive to market forces are more likely to be chosen for investment. As a result, bankruptcies occur more often. Notably, time steps below 50 were omitted because no bankruptcies had occurred at this stage.



(a)



(b)

Fig. 8. (a) Distribution of the number of financial institutions surviving at 100 steps (in each of the 4,000 trials). The number of companies surviving peaks at 20 in the cases where $r_{-depo} = 1.0\%$ and 19 companies in the cases where $r_{-depo} = 0.0\%$ or -1.0%. (b) Distribution of the number of financial institutions surviving at 125 steps (in each of the 4,000 trials). Although the number of companies surviving peaks at 15 for the cases where the deposit rate $= 0.0\%$ and -1.0%, in the -1.0% case, a peak result also forms for total company collapse (zero surviving companies), representing a clear bimodal distribution compared with that in (a).

Figure 9 presents the relationship between the ratio of deposits and ratio of marketable assets in investable surplus at time steps 50 and 75. In this experiment r_{-depo} ranged from -1.0–$+1.5\%$ in steps of 0.25% and 100 trials were executed for each r_{-depo}. According to the decrease in the ratio of deposits, the ratio of marketable assets in investable surplus increases within the range of $-0.5\% < r_{-depo} < +1.0\%$. In the outer range, all investable surplus funds are invested into the marketable assets ($r_{-depo} < -0.5\%$) and are deposited to the central bank ($r_{-depo} > +1.0\%$). Therefore, in a monetary easing environment, each financial institution has a tendency to increase its preference for marketable assets.

5.4. Correspondence Between Simulation Results and Real Cases

The correspondence relationship for this simulation is as follows:

(1) Diversification of investment in securities:

Under an easing monetary policy, regional banks and life insurers in Japan are seeing increased investment in credit, foreign bonds, and domestic stocks [1]. This phenomenon is consistent with the results of our simulation, which revealed that the preference for marketable assets will increase (**Fig. 9**).

(2) Impact on financial system of expansion of market risk:

It is noted that the expansion of market risk as a result of the diversification of investment in securities increases the vulnerability of the financial system [1]. The results of our simulations (**Figs. 7** and **8**) are consistent with such indications.

6. Concluding Remarks

In this study, we focused on the operational risks of increased investment of surplus funds to financial institutions. Specifically, we extended a model focusing on macro shocks to the market to describe decision making regarding funds that are surplus to the operation of financial institutions. Additionally, we analyzed the impact of a decline in the prices of marketable assets on the financial system.

The results revealed that as the current deposit inter-

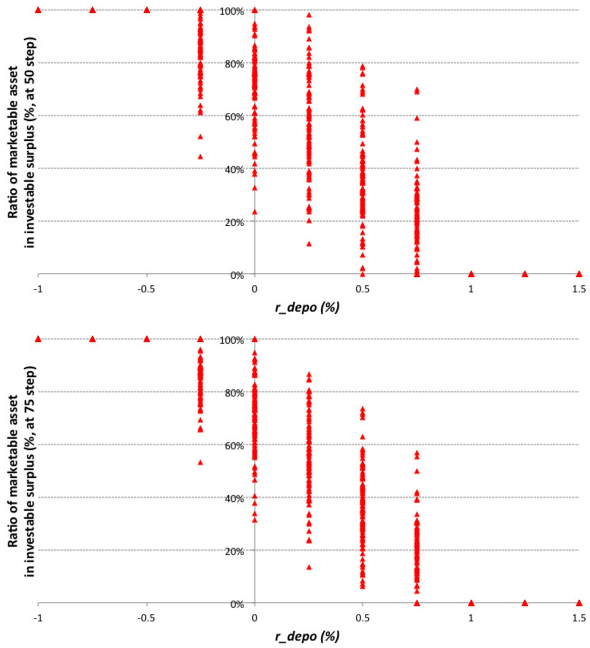


Fig. 9. Relationship between the ratio of deposits and ratio of marketable assets in investable surplus at time steps 50 (above) and 75 (below). $r_{\text{-}depo}$ ranged from -1.0–$+1.5\%$ in steps of 0.25% and 100 trials were executed for each $r_{\text{-}depo}$. According to the decrease in the ratio of deposits, the ratio of marketable assets in investable surplus increases within $-0.5\% < r_{\text{-}depo} < +1.0\%$. In the outer range, all investable surplus funds are invested into marketable assets ($r_{\text{-}depo} < -0.5\%$) and deposited to the central bank ($r_{\text{-}depo} > +1.0\%$).

est rate is lowered, a decrease in the average number of remaining financial institutions can result in an increase in variance. When the current account interest rate decreases as the preference for relatively marketable assets increases, the market sensitivity of each financial institution increases and the potential for lower financial system vulnerability is exploited. Our experiments revealed that although individual financial institutions have reasonable decisions to make to earn profits, the entire financial system can fall into unreasonable situations.

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