Simulation on the effect of financial regulation on stability of financial system and financial institution behavior

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Abstract: After the financial crisis triggered by the Lehman shock, the movement to strengthen financial regulation internationally is becoming active. While there is an appraisal that regulation strengthening has improved the stability of financial institutions, there are views that distort the concerns of lowering the liquidity of the market and incentives of financial institutions. In this paper, we focus on the influence of financial institution's behavior under financial regulation on financial system. The authors propose simulation models of systemic risks expressing financial regulation and the financing/investment behavior of financial institutions. Using this model, scenario analysis is performed based on cases generated from combination of various regulations. Then we approach the issue of trade - off between the stability of the financial system and the liquidity decline.

Keyword: Agent-based Simulation, Systemic Risk, Financial Regulations, Asset Liability Management

1. Introduction

After the financial crisis triggered by the Lehman shock, the movement to strengthen financial regulation internationally is becoming active [Sahara 2015]. While there is an appraisal that regulation strengthening has improved the stability of financial institutions, there are views that distort the concerns of lowering the liquidity of the market and incentives of financial institutions. [Tomiyasu 2016][Miyauchi 2015]. In this paper, we focus on the influence of financial institution's behavior under financial regulation on financial system. The authors propose simulation models of systemic risks expressing financial regulation and the financing/investment behavior of financial institutions [Kikuchi et al. 2015][Kikuchi et al. 2016 a][Kikuchi et al. 2016 b]. Using this model, scenario analysis is performed based on cases generated from combination of various regulations. Then we approach the issue of trade - off between the stability of the financial system and the liquidity decline.

2. Related Work

2.1 Research on Financial Contagion

Theoretical and empirical research on financial crisis propagation and infection includes [Allen and Gale 2000], [Freixas et al. 2000] and [Degryse and Nguyen 2007]. Studies dealing with banking and financial networks as complex networks include [Eisenberg and Noe 2001], [Gai and Kapadia 2007], [Nier et al. 2008], [May and Arinaminpathy 2010] and [Maeno et al. 2012]. Additionally, [Gerog 2013], [Suzuki et al. 2015] and [Hashimoto and Kurahashi 2015] expanded the use of an agent-based model. The following studies analyze the propagation through the inter-bank network (I/B) of collapses of banks and general borrowers with which they have lending relationships: [May and Arinaminpathy 2010], [Maeno et al. 2012], [Suzuki et al. 2015] and [Hashimoto and Kurahashi 2015].

Collapse is often treated as a given. It can be said that a shock is assumed to be caused by individual and idiosyncratic risk factors. Studies also discuss exit from the interbank market due to public sector funding [Hashimoto and Kurahashi 2015] and clearing by the central bank after bankruptcy [Suzuki et al. 2015].

2.2 International financial regulatory reform

In order to prevent the recurrence of the financial crisis, financial regulatory reforms are advancing in a wide range of fields including strengthening the soundness of banks (Basel III) and responding to important financial institutions on the system [Sahara 2015]. These include restrictions on how to suppress the balance sheet size ("balance sheet restriction") and risk amount of financial institutions, such as capital adequacy ratio regulation, leverage ratio regulation, interest rate risk regulation of banking account. While advances in these financial regulatory reforms are alleged to contribute to the stability of the financial system, there is also discussion to point out the decline in market liquidity [Tomiyasu 2016] and the distortion of financial institution incentives [Miyauchi 2015].

3. Definitions

3.1 Asset Liability Management

Asset liability management, which financial institutions perform to maximize earnings, refers to properly controlling the various risks associated with financial transactions. These risks are credit risk, market risk, and liquidity risk, where the first two are caused by investment behavior while the last is caused by cash flow behavior.

3.1.1 Investment and Lending Behavior

Financial institutions engage in direct lending and general lending as part of their financial intermediary function. Additionally, where a bank or securities company owns the marketable assets of entities involved in proprietary trading for profit, these assets constitute its balance sheet. Although each asset is exposed to both credit and market risk, here we refer instead to a classification of risk into general market risk and individual risk [Merton 1974] [Basel 1996]. In the proposed model, we classify subjects of investment into "marketable assets" and "non-marketable assets". Notably, in the investment behavior in this section, handling the intrinsic operation of the marketable assets, and investments

in marketable assets in surplus operating behavior is described later and distinguished.

3.1.2 Financing Behavior

Capital surplus and shortage (funding gap) results from the day-to-day investment behavior and financing situations of financial institutions. The short-term money market provides a means to adjust the financing gap. This is particularly so in the case of Japan, and most especially 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 [Kuroda and Kato 2009].

The proposed model does not include money market dealers and trading rates in contract decisions, but instead assumes that lenders only take into account credit situation and their own tradable amounts of funds.

3.2 Management Constraints

To prevent recurrent financial crisis, measures are being implemented to strengthen the soundness of banks (Basel III) and achieve financial regulatory reform in diverse fields, such as reforms to systemically important financial institutions. In the proposed model, we adopt the capital adequacy ratio (soundness indicators), ROE・Budget (profit indicators) and VaR (risk indicators) as management constraints. The actions of financial institutions under these constraints are shown in Section 4.5.2 (Table 2).

3.3 Bankruptcy Mechanisms

In the proposed model, the bankruptcy factors of financial institutions are as follows: 1) excessive debt; 2) decrease of capital adequacy ratio to below a certain value; and 3) lack of funds post-funding to continue procurement. The first factor refers to general loans and inter-bank loans that are written off because they cannot be absorbed by the company's capital balance. This first factor thus resembles that handled by the model of May and Arinaminpathy (hereafter the M-A Model) [May and Arinaminpathy 2010]. Taking the case of Japan as an example, the second factor means the capital adequacy ratio consistent with uniform international standards, which exceeds 8% [FSA webpage]. The third factor describes a situation where a company cannot resolve its lack of funds in the short-term money market (i.e., the company faces a financing collapse). Fig.1 compares bankruptcy factors with 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 1) lending networks to businesses and 2) interbank 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 deposit 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 difference between balance sheet debits and credits).

The authors have proposed the extension model based on the M-A model to analyze aspects of bankruptcy chain through changes in the balance sheets of individual financial institutions [Kikuchi et al. 2015].

The presented model has the following characteristics: 1) Each financial institution has a simplified balance sheet and engages in short-term lending and borrowing through the interbank network. 2) Collapse of each financial institution is permitted to observe the impact of such collapse 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, a feature that is important in representing the chain of failure.

Additionally, our model expresses:

1) Deterioration in the financial and credit situation of financial institutions through fluctuations in the market prices of assets held (capital adequacy ratio);
2) Increase in cash flow shortfall and liquidity risk due to deterioration of the financing environment in the I/B market;
3) Central bank funding to prevent bankruptcy.

Thus our model has become an agent-based model that focuses on the endogenous mechanisms of the financial crisis (Fig. 2).

Notably, because in this paper, we look at the impact of surplus operating behavior and price fluctuations of market assets on the financial condition and cash flow of financial

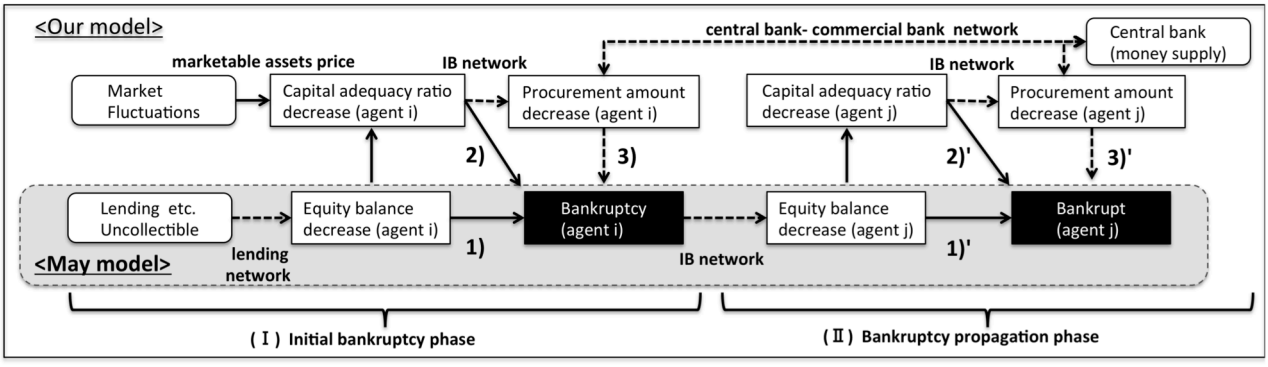


Fig. 1 Bankruptcy factors in the proposed model: 1) Decrease in equity balance as in the model of May; 2) Decrease in capital adequacy ratio; and 3) Decrease in procurement volume by institutions with a shortage of funds

institutions, we do not deal with trading networks of non-marketable assets and trading networks between the central bank and commercial financial institutions.

4.2 Agents

In the model of May [May and Arinaminpathy 2010], each financial institution

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

has a simplified balance sheet as follows (Table 1). Each balance sheet consists 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) Short-Term Investment SI_i; and 7) Short-Term Financing SF_i.

Financing gap and fund surplus/shortage institutions are then defined as below:

$$Gap_i = D_i + E_i - CA_i - nonMA_i - MA_i^{bookvalue}$$
$$C^{surplus} = \{\ a\_i|Gap_i >= 0\ \}$$
$$C^{shortage} = \{\ a\_i|\ Gap_i < 0\ \}$$

Note that the status of each financial institution remains unchanged.

We also define unrealized profit or loss (UP_i), capital adequacy ratio (CAR_i), income profit (IP_i) and ROE (ROE_i):

$$UP_i = MA_i^{t\ marketvalue} - MA_i^{bookvalue}$$
$$CAR_i = (E_i + UP_i + \Sigma\, CP_i)/(non\ MA_i + MA_i^{bookvalue})$$
$$IP_i = \beta * MA_i^{bookvalue} + \gamma * nonMA_i$$
$$ROE_i = IP_i / E_i$$

where β and γ denote the rates of return for marketable and non-marketable assets, respectively. $MA_i^{t\ marketvalue} = (MA_i^{bookvalue}/P_0) * P_t$, where P_t is the market price of marketable assets in step t.

Additionally, financial institutions face demands that they maintain a minimum capital adequacy ratio ($CAR\text{-}demand_i$). In the 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 surplus requested of institutions facing a capital shortage.

Table 1 Balance sheet items of commercial financial institutions

Debit	Credit
Cash CA	Debt D
Non-marketable asset nonMA	
Marketable asset $MA^{bookvalue}$	Equity E
Short term investment SI	Short term financing SF

4.3 Networks

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

$$W_i^{Interbank} = \{\ a\_j|m\_ij = 1\ \}$$

and tries to eliminate the funding gap between itself and connected institutions. Then, $M=(m\_ij)$ is the adjacency matrix of the I/B network.

4.4 Financing Behavior

4.4.1 Financing of Shortage Institutions by Surplus Institutions

(Step1) Institution agents that are shortage institutions make requests for financing from surplus institutions that lend to the interbank network and evenly split their own financing gap. The minimum order size is in a specified range.

Shortage institution a_i makes requests for financing to surplus institution a_j ($amount_i^j > 0$)

$$\mathrm{Order}\ (\mathrm{i}, \mathrm{j}, amount_i^j)$$

Additionally, a_i denotes all surplus institutions that lend to the interbank network and obey the instruction to evenly split the value of their own financing gap. Here,

$$(a\_i\ , a\_j\ ) \in\ C^{surplus} \times C^{shortage}$$

δ: minimum order size $\in$ Z, $amount_i^j = \max(\mathrm{ceil}(Gap_i' / \#\,(C^{surplus} \cap W_i^{Interbank})), \delta) \in$ Z

(Step2) a_j checks the financial condition and amount of self-funding available for a_i to perform the contract judgment.

• *Contractual conditions:*

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

$amount_i^j =< Gap_j' - \Sigma amount^{j\ other\ implemented\text{-}orders}$

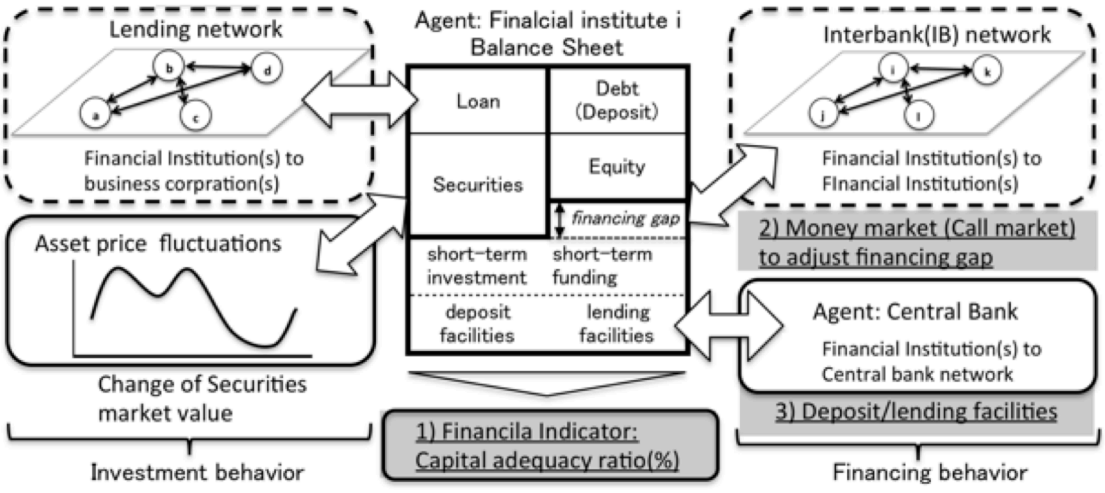


Fig. 2 Conceptual model: the model explicitly describes ALM actions, such as investment and financing activities. Funding changes and the changes to the central bank's financial situation due to price fluctuations in the asset market express the impact of ALM actions on operational collapse.

• *non-Contractual conditions:*
Other than those above

Then, transactions to which a_j has already committed $amount^{j\ other\ implemented\text{-}orders}$.

(Step1') This step is an alternate to Step1. If non-contract, a_i will 1) change the order destination to another surplus institution a_k, or/and 2) reduce the order amount.

Order (i, j, $amount_i^j$) → Order' (i, k, $amount_i^k$)
Order (i, j, $amount_i^j$) → Order' (i, j, $amount'^j_i$)
Order (i, j, $amount_i^j$) → Order' (i, k, $amount'^k_i$)

Then, $k \in C^{surplus} \cap W_i^{Interbank}$, $amount'_i$ = floor ($amount_i$ / 2) >=δ

(Step3) If a_i cannot meet $Gap_i' >= 0$ the result is collapse.

4.4.2 Other Short-Term Investment and Funding

Assuming cross-trades (both built transactions) are carried out [Kuroda and Kato 2009], we consider the following short-term funding or investment transactions between financial institutions. A certain percentage of the balance sheet amount then becomes the upper limit.

Between shortage–shortage and surplus–surplus institutions:
a_i is the upper limit of l times between a_j of the same status, and generates the following order:

Order (i, j, $amount_i^j$) or Order (j, i, $amount_j^i$)

Between surplus–shortage institutions:
a_i is the upper limit of l times between a_j of the same status, and generates the following order:

Order (i, j, $amount_i^j$)

Then,

$amount_i$=ceil(($CA_i + MA_i^{bookvalue} + nonMA_i$)*ε),
l = floor(($CA_i + MA_i^{bookvalue} + nonMA_i$)*ζ/ amount$_i$)

4.5 Investment Behavior

4.5.1 Outline

Financial institutions make investment decisions regarding marketable assets for each step under the following management constraints: a) capital adequacy ratio; b) VaR; c) ROE; d) market outlook.

Here, the range of possible values of marketable assets is as follows:

$$0 < MA'^{bookvalue}_i <= MA_i^{bookvalue} + CA_i$$

Additionally, the balance of non-marketable assets is a constant, untreated lending behavior.

4.5.2 Formulation of Management Contract and Market Outlook

Various constraints and market outlook are defined as shown in Table 2.

$$VaR_i = MA_i^{bookvalue} * \sqrt{n} * (r_{avg} - \eta * \sigma_m)$$

Furthermore, r_{avg} and σ_m are calculated from the daily return of P_t (sample period: m_{days}).

$$r_{avg}^t = \frac{1}{m}\sum P_t / P_{t-1}$$

$$\sigma_m^t = \sqrt{\frac{1}{m}\sum (P_t/P_{t-1} - r_{avg}^t)^2}$$

Table 2 Management Contract and Market Outlook

Contracts	Formulation
a) CAR	$CAR_i > CAR\text{-}demand_i$
b) VaR	$VaR_i < E_i * \xi$
c) ROE・Budget	IP_i>Budget taget y_i
d) Market Outlook	$f = r_{exp} - \lambda_i * \sigma_m$

4.5.3 Investment Decision-Making

Under the above constraints, the financial institution decides to buy, sell or hold market assets in accordance with the flow chart below (Fig.3):

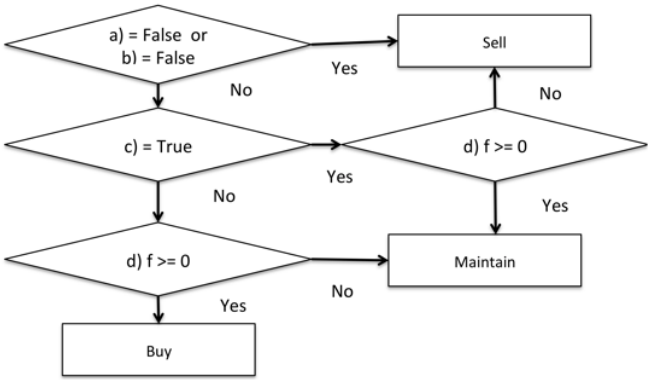


Fig. 3 Flowchart of investment decisions

4.5.4 Decision Regarding Buying and Selling Amount

If buying or selling has been selected in the previous section, the amount of buying and selling is as described below:

Buying Amount: Compare current holdings of marketable assets, calculated from the upper limit of the VaR constraint, to buy θ% of the difference.

Selling Amount: A sale resulting from conflict with the capital adequacy ratio constraints and VaR constraints should comprise only those marketable assets sufficient to meet each of the constraints. Additionally, a sale resulting from the conflict with the ROE budget constraint should sell sufficient marketable assets to exceed the budget.

4.6 The Effects of Bankruptcy

4.6.1 Individual Bankruptcy

If the capital adequacy ratio is equal to or less than the threshold value, or if the funding gap is not filled, for example owing to a failure of cash flow, financial institution a_i will experience bankruptcy:

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

4.6.2 Chain Reaction Collapse

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

$$E_j' = E_j - SI_j^i$$

If the following conditions are satisfied, financial institution a_j also suffers bankruptcy and a chain reaction collapse occurs.

$$E_j' < 0 \text{ or } Gap_j' < 0 \quad or \quad CAR_j < \alpha$$

4.7 Evaluation

This paper considers situations with and without balance sheet restriction to evaluate the loads of individual financial institutions and of the financial system. Specifically, number of financial institutions surviving (number of failed financial institutions) is used as a macro indicator in the model.

Also, as a macro index related to the liquidity of marketable assets, refer to [Tomiyasu 2016], adopt the trading volume of marketable assets of each financial institution and define it as total trade volume as follows:

$$Gross\ amount_t = \sum_i |buy\ or\ sell\ amount_i^t|$$

5. Analysis of Model Behavior

This simulation employs the following steps to implement individual attempts to undertake investment behavior in accordance with the operating limitations described in Section 4.5.2 (Table 2). Furthermore, we compare the case assuming the balance sheet restriction ("Case 1: without BS restriction") and without limiting the parameter occurrence range of marketable assets ("Case 2: with BS restriction"). We will indicate the overall trend of the stability of the system in each case (Section 5.3) and show the results of individual trials and overall trials on liquidity (Section 5.4).

5.1 Price Time Series of Marketable Assets

The price of risky assets is assumed to follow in the discretized stochastic differential equation below [Luenberger 1997]:

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

where t is time step $(t = -m+1, \ldots, 0, 1, \ldots, T)$, j is 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 Δt=1/250, T=125 (assuming 6 months is the budget-closing period for a bank account). Additionally, taking into account long-term government bond yield levels and stock markets in each country: r_f =2%, σ =25%. 100,000 sample paths were generated and marketable asset prices in the final step are used to adopt the lowest price time series (Fig. 4).

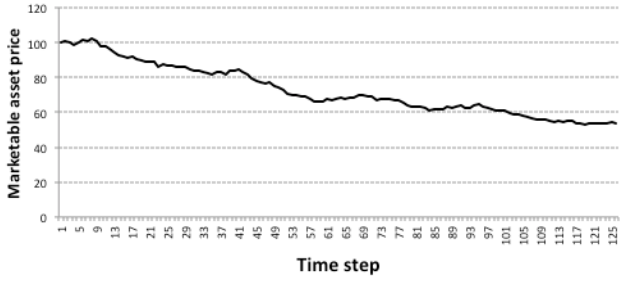


Fig. 4 Price time series of marketable assets employed in this simulation. Implementation totaled 100,000 trials and the adopted price time series became the lowest price.

5.2 Common Settings

Table 3 gives the parameters used in our experiment. Two patterns of parameter occurrence ranges of marketable assets were prepared corresponding to cases where balance sheet constraints were imposed and not imposed. In this simulation, we focus on financial institutions that constitute an important and core network on the system, so we refer to [FSB webpage] and set the number of financial institutions to 20 companies(#1–#20, including 10 each of both surplus and shortage institutions), and the I/B network is a complete graph. In terms of the financing gap, because surplus institutions outnumber shortage institutions, surplus institutions were subjected to the following adjustment:

(Financing gap adjustment)=$\Sigma_{C^{surplus}}(nonMA_i + MA_i^{bookvalue})$* ι / #

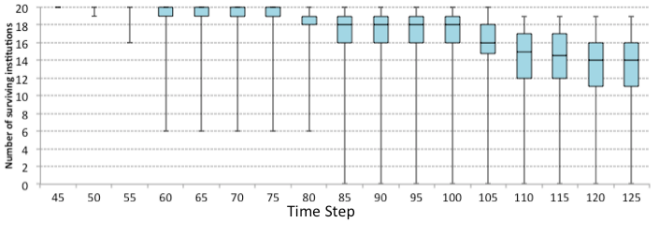
Additionally, for balance sheet items outside the table, we set the capital based on a given capital adequacy ratio. Liabilities taking into account the financing gap were determined by back calculation such that credit and debit match. Following that, we set short-term investment and funding in the following: α: 0%; β: 1.2%; γ: 1.0%; δ: 1; ε: 5%; ζ: 50%; η: 2.33; θ: 10%; ι: 10%; n_{days}: 10; m_{days}: 16.

Table 3 Parameter set used in this simulation.

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

5.3 Stability of financial system

Here, for the two cases of without BS restriction case and with BS restriction case, the parameters shown in Table 3 were generated 100 times each and the simulation was carried out. Fig. 5 shows a box-and- whisker plot for every 5 steps for the number of remaining financial institutions representing the stability of the system(above: case 1 without BS restriction, below: case 2 with BS restriction). Without BS restriction case shows that the variation of the remaining number is large and that it is more distributed in the range where the remaining number is small. The average remaining number in the final step is 12.8 for without BS restriction case and 19.7 for with BS restriction case. With BS restriction case has a lower number of failed financial institutions. In this regard, it was shown that the stability of the financial system can be improved by imposing balance sheet restriction.



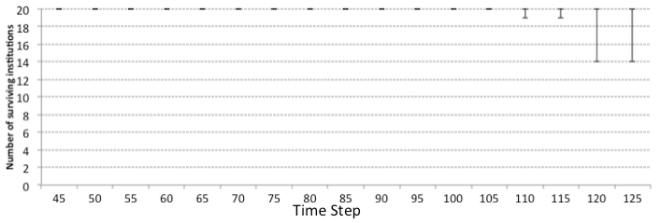


Fig. 5 Box-and-whisker plot of the number of financial institutions surviving at each five step interval (above: case 1 without BS restriction, below: case 2 with BS restriction). It can be seen that without BS case has a greater variation in the residual number and is more distributed in the range where the number of residuals is small. Notably, time steps below 45 are omitted because no bankruptcies had occurred at this stage.

5.4 Liquidity

5.4.1 Individual trials

In this section, we confirm the impact on the liquidity of marketable assets for each case (with/without BS restriction). As in the previous section, we used the same initial parameter set according to Table 3 and compared the results for the corresponding one sample trial.

Fig. 6 shows the trends of the gross trading volume "Gross amount" of marketable assets, which is a macro index of liquidity, for two patterns of Case 1: witout BS restriction and Case 2: with BS restriction. As for the tendency common to each case, with each financial institution, 1) initially the inclination to decision to increase marketable assets due to ROE · budget constraint, mainly increased purchase volume from the start, 2) as a result of the increase in VaR due to declines in market price and increased volatility, the amount of sales increased due to temporary VaR constraints. On the other hand, the total value of the total trading volume at the final step is 1,326 in without BS restriction case, 480 in with BS restriction case, so the latter case is more limited.

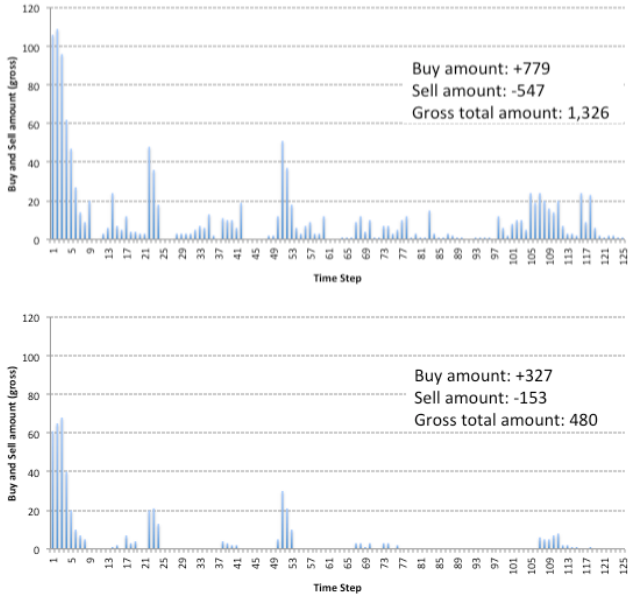


Fig.6 Trends in total trading volume of marketable assets (above: without BS restriction case, below: with BS restriction case). Initially due to ROE · budget constraints the decision to increase marketable assets increased, mainly purchase volume increased. Thereafter, due to declines in market price and increase in VaR due to volatility increase, there were also circumstances where the amount sold increased due to violation of temporary VaR constraints. On the other hand, the total value of the total trading volume up to the final step was limited in the case of with BS restriction.

5.4.2 Overall trials

Based on the individual trials in the previous section, we carried out the simulation by generating the parameters shown in Table 3 100 times for each of 2 cases (Case 1: without BS restriction and Case 2: with BS restriction) Table 4 below .

Table 4 Average value and standard deviation of the total trading volume of marketable assets. As with the sample trials in the previous section, the total trade volume at the final step is limited compared with the case without BS restriction in the case of BS constraint, about 40% .

Statistics	Case	
	without BS restriction	with BS restriction
Average	1,217.5	442.1
S.D.	202.2	49.3

As with the sample trials in the previous section, the total value of the total trading volume at the final step was limited to about 40% in the case with BS restriction, as compared with the case without BS restriction. In this regard, imposing the balance sheet restriction suggests that the trading behavior of each financial institution is suppressed and the liquidity of marketable assets may decline.

5. Concluding Remark

In this paper, we expanded a simulation model of systemic risk that expresses the financial regulation and financing/investment behavior of financial institutions proposed by the authors [Kikuchi et al. 2015] [Kikuchi et al. 2016 a] [Kikuchi et al. 2016 b] and proposed a model that expresses the stability of the financial system and the liquidity of marketable assets.

In addition, under the various management constraints and market trends, we carried out scenario analysis for both cases where the balance sheet restriction is not assumed ("Case 1: without BS restriction") and assumed ("Case 2: with BS restriction"), depending on the parameter occurrence range of marketable assets.

In the overall trend on the stability of the financial system, with BS restriction case has been suppressed for the number of failed financial institutions, and it has been shown that by imposing a balance sheet restriction, the stability of the financial system can be enhanced .

On the other hand, in individual trials and overall trials on liquidity of marketable assets, with BS restriction case was limited with respect to total trade volume in comparison with cases without BS restriction case. The liquidity of marketable assets could be reduced by imposing a balance sheet restriction.

These results are consistent with the previous study [Tomiyasu 2016] that there is a concern that market liquidity will be lowered, while there is an evaluation that the regulation strengthening process has improved the stability

of financial institutions.

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