Study on Bank's Risk Incentives and Deposit Trends Considering Japanese Depositors' Behavioural Biases

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Hiroki Seta
Department of Business Economics, School of Management, Tokyo University of Science

ABSTRACT

Anxiety that depositors will not always be compensated during a recession causes some depositors to withdraw their deposits over-defensively. Focusing on the behavioural biases of Japanese depositors in the situation where bank runs are expected to occur at a bank under the deposit insurance system, we analyse a bank's risk incentive problem from the aspect of their deposit trends. In evaluating the bank equity as an option price that incorporates depositors' trends measured by using cumulative prospect theory, we can measure the bank's risk incentives by considering their behavioural biases. The evaluation of prospect value by cumulative prospect theory Choquet integral and the option pricing model on perpetual type are employed in this study. A comparison of several numerical examples using incentive contract and bank credit spreads reveals that a bank's risk incentives could cause the bank to exhibit risky behaviour, even in the situation where withdrawals with awareness of deposit protection under the deposit insurance system and overly defensive withdrawals by depositors sceptical of this system itself will occur simultaneously.

Keywords: Corporate finance; Cumulative prospect theory; Option pricing; Risk incentive.

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1. INTRODUCTION

Even though the deposit insurance system (DIS) protects some or all of deposits, some depositors withdraw their deposits excessively. The deposit insurance schemes with insufficient funding and its potential delays in depositor compensation stimulate depositors' behavioural biases. During bank runs, the deposit amount not guaranteed by the DIS is not withdrawn reasonably and uniformly by depositors as an expected value considering individual circumstances but the effects of loss aversion bias may cause some depositors to decide to withdraw their deposits overdefensively. Depositors' withdrawals with such tendency will be seen globally, for example, the financial crisis caused by the bankruptcy of Lehman Brothers in 2008. This is even reflected in the situation of lockdown against the spread of COVID-19 infection in 2020 in the United Kingdom, Spain, France and so on. Therefore, the behavioural biases of depositors must be considered on depositors' trends where bank runs are likely to occur or occurring.

In 2019, the Central Council for Financial Services Information conducted the Financial Literacy Survey, an online survey on the tendency of Japanese behavioural bias, on 25,000 individuals aged 18 to 79 years. The following question was asked: 'Suppose you invested 100,000 yen. You would either obtain a capital gain of 20,000

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yen or a capital loss of 10,000 yen at a 50 percent probability. What would you do?' The options were 'I would invest' and 'I would not invest'. Of the respondents, 77.3 percent answered that they would not invest. The survey results reveal that Japanese, especially women, would generally have a strong behavioural tendency of loss aversion. A Japanese custom called 'Tansu Yokin' has been observed daily for a long time. A chest of drawers is expressed as 'Tansu' in Japanese. Thus, 'Tansu Yokin' means that they keep their money in the chest of drawers at home without investing. What they think 'Tansu Yokin' is relieved may be a strong loss aversion bias.

Peia and Vranceanu's (2019) experimental results show that bank runs may not always be triggered by information transmission and external shocks touted through mere panic. Additionally, they mention that when deposit insurance scheme makes depositors unsure that the scheme guarantees all depositors, uncertainty such that the depositors don't really know the actual amount to be compensated would result in a bank run with high probability. It also suggests overdefensive withdrawals of depositors. However, the withdrawals limit in Automatic Teller Machines (ATMs) may create strong awareness causing depositors to rush to the bank to withdraw before losing the ability to do so. Thus, the depositors who think about bank runs tend to withdraw the amount excluding the guaranteed or near the total amount.

The excessive loss caused by speculative behaviour of the bank compels the Deposit Insurance Corporation (DIC) to prepare bank liquidation. Such a chain of banks' failures will trigger a financial crisis. Moreover, depositors' anxieties may amplify the effect of loss aversion bias, leading bank runs with withdrawals over the compensation amount. However, neither the bank's speculative behaviour nor its failure is immediately known to all depositors. This is because the depositors think that the DIS's protection is recognised as sufficient. Another reason is the status quo bias that depositing at this bank has no issues, and hence, the depositors themselves do not monitor the bank until they know that DIC begins liquidating it, thereby weakening the market discipline. Then, we recall that a bank moral hazard problem is tackled within the framework of principal-agent theory, under which depositors are principals (lenders) and the bank is the agent (borrower). Hence, bank's risk incentives (risk-shifting incentives) are fermented in the bank.

The remainder of this paper is organised as follows. Section 2 discusses bank's risk incentive problem. Section 3 shows that deposit trends considering Japanese depositors' behavioural biases can be incorporated in Seta and Inoue's (2020) findings using perpetuity of option. Moreover, Section 4 presents the results of numerical simulations assuming overly defensive deposit withdrawals. Finally, Section 5 concludes the paper.

2. BANK'S RISK INCENTIVE PROBLEM

Since Jensen and Meckling (1976) dealt with the risk-shifting problem (or the asset substitution problem) as an incentive problem on hidden action, the risk incentive problem has been discussed in terms of conflicting interests between borrowers and lenders. Concerning financial contracting, the risk incentive problem arises when the borrower increases the project risk by affecting its profit-sharing at the expense of the lender. Then, choosing a risky project that increases both project's risk and firm equity value may cause the invested project to fail. In a financial situation where the borrower itself realises that business recovery is necessary to survive, an excessive loss incurred with such a failure may cause the borrower's firm to go bankrupt in the worst case. Thus,

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more attention is paid to the action and impact of borrower's risk incentive that induces increasing project risk.

Various studies and arguments from the definition of the bank's risk incentive to its circumstances have been conducted. For example, Flood (1990) suggested that bankers have risk incentive unmitigated to increase the risk of bank equity, whereas Federal Deposit Insurance Corporation has the opposite incentive to repress bank's risk-oriented behaviour. Moreover, John et al. (1991) emphasised that the nature of insurance premium as a sunk cost for a bank can not be expected to change the incentive it faces. Furthermore, Seta and Inoue (2020) and Seta (2021) discussed the situation in which banks' risk incentives become chronic and the design of incentive contracts that removes them, respectively.

Regarding option pricing theory for assessing firm equity and measuring risk incentive, Flood (1990) and Miyake and Inoue (2012), among others, adopted the Black-Scholes formula or the option pricing formula on down-and-out option. However, note that the option pricing formula with no barrier or maturity implicitly assumes a project with infinite volatility or company dissolution at the end. Thus, it hinders the establishment and analysis of more realistic models; thus, the perpetual down-and-out option pricing formulae that may resolve these inconveniences are used in this study. Furthermore, Ziegler (2004) showed in detail the method with these perpetual option pricing formulae and the properties related to the bankruptcy probability of borrower's company that can be obtained as risk-neutral probability.

Regarding the relationship between the DIS and bank's risk incentives, many authors argued that the presence or absence of the relationship between deposit insurance premium and project's risk may be related to mitigation or occurrence of the bank's risk incentives. For instance, Marcus and Shaked (1984) and Ronn and Verma (1986) calculated appropriate deposit insurance premium by using the put option, and they referred to the impact of risk incentive on fixed-rate deposit insurance based on the risk-oriented bank. Meanwhile, John et al. (1991) concluded that the fair price of deposit insurance does not affect bank's risky behaviour.

Since the work of Diamond and Dybvig (1983), bank runs have been dealt with as an equilibrium phenomenon that is fundamentally related to bank illiquidity. For example, Postlewaite and Vives (1987) considered a prisoner's dilemma-type situation where only one equilibrium has a positive probability of bunk runs. More specifically, in the process leading up to bank runs, when many people rush to the bank, a few events follow, including an injection of taxpayers' money, a bank liquidation by DIC, or an endogenous bankruptcy. In fact, in 2003, tax money was actually injected into Resona Bank, Ltd., in Japan before the endogenous bankruptcy. Moreover, we suppose that the bank's liquidation by DIC occurs earlier than the tax injection or the bank's endogenous bankruptcy. Hence, we treat it as if the bank runs are occurring or likely to occur. Our study aims to analyse whether the bank's risk incentive problem will occur even with overly defensive withdrawals of deposits. Therefore, we do not pursue the property of equilibrium phenomenon on bank runs but focus on the withdrawal behaviour of depositors, especially the distribution of depositors' trends in a situation in which bank runs are occurring or likely to occur.

3. NUMERICALLY MEASURING BANK'S RISK INCENTIVES CONSIDERING DEPOSITORS' BEHAVIOURAL BIASES

Using cumulative prospect theory Choquet integral, we evaluate depositors' trends in

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this section. The details of the cumulative prospect theory and the cumulative prospect theory Choquet integral are found in Tversky and Kahneman (1992) and Grabisch and Labreuche (2002), respectively. First, for a finite set $\{x_1, \cdots, x_n\}$, its power set $\mathcal{P}(\{x_1, \cdots, x_n\})$, a finite fuzzy measure $m^+ : \mathcal{P}(\{x_1, \cdots, x_n\}) \to [0,1]$ and a $\mathcal{P}(\{x_1, \cdots, x_n\})$-measurable function $f_0 : \{x_1, \cdots, x_n\} \to [0, \infty)$ rearranged in $f_0(x_{i_0}) := 0 \le f_0(x_{i_1}) \le \cdots \le f_0(x_{i_n})$, the form

$$(\boldsymbol{C}) \int \boldsymbol{f_0}\, \boldsymbol{dm^+} := \sum_{j=1}^{n} \left(\boldsymbol{f_0}\left(\boldsymbol{x_{i_j}}\right) - \boldsymbol{f_0}\left(\boldsymbol{x_{i_{j-1}}}\right)\right) \boldsymbol{m^+}\left(\left\{\boldsymbol{x_{i_j}}, \cdots, \boldsymbol{x_{i_n}}\right\}\right) \qquad (1)$$

is defined as Choquet integral. For the finite fuzzy measure $\boldsymbol{m^-}(\{\boldsymbol{x_{i_1}}, \cdots, \boldsymbol{x_{i_m}}\}) := \boldsymbol{1 - m^+}(\{\boldsymbol{x_1}, \cdots, \boldsymbol{x_n}\} - \{\boldsymbol{x_{i_1}}, \cdots, \boldsymbol{x_{i_m}}\})$, $\boldsymbol{\mathcal{P}}(\{\boldsymbol{x_1}, \cdots, \boldsymbol{x_n}\})$-measurable functions (i.e. value function) $\boldsymbol{f} : \{\boldsymbol{x_1}, \cdots, \boldsymbol{x_n}\} \to \mathbb{R}$, $\boldsymbol{f^+} := \boldsymbol{max}(\boldsymbol{f}, \boldsymbol{0})$ and $\boldsymbol{f^-} := \boldsymbol{min}(-\boldsymbol{f}, \boldsymbol{0})$,

$$\boldsymbol{C_{CPT}}(\boldsymbol{f})(\boldsymbol{m^+}, \boldsymbol{m^-}) := (\boldsymbol{C}) \int \boldsymbol{f^+}\, \boldsymbol{dm^+} - (\boldsymbol{C}) \int \boldsymbol{f^-}\, \boldsymbol{dm^-} \qquad (2)$$

is defined as the cumulative prospect theory Choquet integral when $f(x_{i_1}) \le \cdots \le f(x_{i_k}) \le 0 \le f(x_{i_{k+1}}) \le \cdots \le f(x_{i_n})$ is reallocated. With respect to x_{i_j}, probability p_{i_j} that x_{i_j} occurs and the probability weighting function $w(p, \gamma) := \frac{p^\gamma}{(p^\gamma + (1-p)^\gamma)^{\frac{1}{\gamma}}}$, m^- and m^+ satisfy

$$m_j{}^- := m^-\left(\left\{x_{i_j}, \cdots, x_{i_k}\right\}\right) = \begin{cases} w(p_{i_1}, \gamma^-) & (j = 1) \\ w\left(p_{i_1} + +p_{i_j}, \gamma^-\right) & (2 \le j \le k) \end{cases}$$

$$\boldsymbol{m_j{}^+} := \boldsymbol{m^+}\left(\left\{\boldsymbol{x_{i_j}}, \cdots, \boldsymbol{x_{i_n}}\right\}\right) = \begin{cases} \boldsymbol{w}\left(\boldsymbol{p_{i_j}} + +\boldsymbol{p_{i_n}}, \boldsymbol{\gamma^+}\right) & (\boldsymbol{k+1} \le \boldsymbol{j} \le \boldsymbol{n-1}) \\ \boldsymbol{w}(\boldsymbol{p_{i_n}}, \boldsymbol{\gamma^+}) & (\boldsymbol{j = n}) \end{cases} \qquad (3)$$

where γ^+, $\gamma^- \in [0,1]$ meet the condition such that m^- and m^+ are finite fuzzy measures or $w(p, \gamma^+)$ and $w(p, \gamma^-)$ are at least monotonically increasing with respect to p in $[0,1]$. Then, for $f^-(x_{i_{k+1}}) = 0$ and $f^+(x_{i_k}) = 0$,

$$\begin{aligned} C_{CPT}(f)(m^+, m^-) &= \sum_{j=k+1}^{n} \left(f^+\left(x_{i_j}\right) - f^+\left(x_{i_{j-1}}\right)\right) m_j{}^+ - \sum_{j=1}^{k} \left(f^-\left(x_{i_j}\right) - f^-\left(x_{i_{j+1}}\right)\right) m_j{}^- \\ &= -\sum_{j=k}^{k} f^-\left(x_{i_j}\right) m_j{}^- + \sum_{j=2}^{k} f^-\left(x_{i_j}\right) m_{j-1}{}^- + \sum_{j=k+1}^{n} f^+\left(x_{i_j}\right) m_j{}^+ - \sum_{j=k+1}^{n-1} f^+\left(x_{i_j}\right) m_{j+1}{}^+ \\ &= m_1{}^- f(x_{i_1}) + \sum_{j=2}^{k} (m_j{}^- - m_{j-1}{}^-) f\left(x_{i_j}\right) + \sum_{j=k+1}^{n-1} (m_j{}^+ - m_{j+1}{}^+) f\left(x_{i_j}\right) + m_n{}^+ f(x_{i_n}) \end{aligned}$$

gives a conventional evaluation formula for prospect value based on cumulative prospect theory, although the definition of value function is different. The effects of loss aversion bias and status quo bias are evaluated as $-(C) \int f^-\, dm^- =$

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$m_1^- f(x_{i_1}) + \sum_{j=2}^{k}(m_j^- - m_{j-1}^-) f\left(x_{i_j}\right)$ and $(C)\int f^+ \, dm^+ = \sum_{j=k+1}^{n-1}(m_j^+ - m_{j+1}^+) f\left(x_{i_j}\right) + m_n^+ f(x_{i_n})$, respectively.

Next, assuming a bank with n depositors and a set E considering of all the causes of deposits and withdrawals, the finite subset $\{e_1, \cdots, e_m\}$ of E is treated as a situation in which any specific events have occurred. The deposit trend of depositor A_i $(i = 1, \cdots, n)$ is evaluated by value function $v^{(i)} : \{e_1, \cdots, e_m\} \to (-1, \infty)$. Thus, it can be described that depositor A_i withdraws $\left|v^{(i)}(e_j)\right| \times 100$ percent deposit in the case of $v^{(i)}(e_j) < 0$, deposits additionally $\left|v^{(i)}(e_j)\right| \times 100$ percent of his/her deposit in the case of $v^{(i)}(e_j) > 0$ and does nothing to his/her own deposit in the case of $v^{(i)}(e_j) = 0$. For γ^+, $\gamma^- \in [0,1]$ such that m^+ and m^- satisfying equation (3) are the finite fuzzy measures or $w(p, \gamma^+)$ and $w(p, \gamma^-)$ are at least monotonically increasing with respect to p in $[0,1]$, the prospect value $C_{CPT}(v^{(i)})(m^+, m^-)$ is equivalent to the evaluated value of depositor A_i's trend, taking into account of loss aversion bias and status quo bias in situation $\{e_1, \cdots, e_m\}$ where bank runs are occurring or likely to occur. Hence, from the aspect of depositors' trends, the situation where bank runs are occurring or likely to occur is grasped as fuzzy set.

Then, assume that the bank invests deposits and capital increases in a project and that the value of invested project S_t follows the geometric Brownian motion with constant drift μ and volatility σ. Consequently, for the standard Wiener process dZ_t, the value of invested project S_t satisfies the following stochastic differential equation

$$\boldsymbol{dS_t = \mu S_t dt + \sigma S_t dZ_t} \tag{4}$$

Additionally, a deposit is interpreted as a claim to bank, so that for interest income r^* and deposit distribution $u := \{u, \cdots, u_n\}$, the face value of depositor A_i's claim $X_i(t)$ $(i = 1, \cdots, n)$ is evaluated as $X_i(t) = u_i S_0 e^{r^* t}$. By letting v_i be $1 + C_{CPT}(v^{(i)})(m^+, m^-)$, depositor A_i's deposit trends are reflected in the face value of claim $v_i X_i(t)$. For the capital increase rate x $(x > 0)$ and bank liquidation cost β $(0 < \beta < 1)$, $\sum_{i=1}^{n}(1-\beta)(1+x)v_i X_i(t)$ is calculated as the total amount of investment in the project. Concerning the bank's lending rate r $(r > r^*)$, the money has been deposited in the bank long enough that the deposit spread $r - r^*$ earns liquidation cost α $(0 < \alpha < 1)$. The liquidation cost α is greater than bank's liquidation cost β and occurs when the bank chooses endogenous bankruptcy due to bank runs.

Based on the compensation amount to depositor A_i by DIS $Y_i(t)$ $(i = 1, \cdots, n)$, knockout price equal to the project value when DIC liquidates bank $K(t)$, perpetual down-and-out call option value C_i and perpetual American put option value P_i and $\gamma^* := \frac{2(r-r^*)}{\sigma^2}$, the depositor behavioural biases are newly incorporated into the results of Seta and Inoue(2020) below.

$$\boldsymbol{C_i} = \begin{cases} \boldsymbol{(1-\beta)(1+x)(v_i u_i)S} \\ \quad \boldsymbol{+\left((1+x)v_i X_i(t) - (1-\beta)(1+x)(v_i u_i)K(t)\right)\left(\frac{S}{K(t)}\right)^{-\gamma^*}} & \boldsymbol{(S \geq K(t))} \\ \boldsymbol{(1+x)v_i X_i(t)} & \boldsymbol{(S < K(t))} \end{cases} \tag{5}$$

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$$P_i = \left((1+x)Y_i(t) - (1-\beta)(1+x)(v_i u_i)K(t)\right)\left(\frac{S}{K(t)}\right)^{-\gamma^*}$$

Thus, the total bank equity is evaluated as $C := \sum_{i=1}^{n} C_i$, and the bank's risk incentives where bank runs are likely to occur is numerically measured as $\sum_{i=1}^{n} \frac{\partial C_i}{\partial \sigma}$. The risk-neutral probability $\left(\frac{S}{K(t)}\right)^{-\gamma^*}$ is calculated as the probability of DIC's liquidation in which runs on the bank are likely to occur. The insurance scheme has three different forms: fixed-ratio deposit insurance coverage with fixed rate $a\,(0 < a \leq 1)$, maximum insurance coverage limit with maximum amount $M\,(M > 0)$ and deduction with rate $d\,(0 \leq d < 1)$. The amount of compensation for depositor A_i's deposit $Y_i(t)$ varies as follows.

$$\boldsymbol{Y_i(t)} = \begin{cases} \boldsymbol{a\left(v_i X_i(t)\right)} & (\textbf{fixed} - \textbf{ratio deposit insurance coverage}) \\ \boldsymbol{min\{v_i X_i(t), M\}} & (\textbf{maximum insurance coverage limit}) \\ \boldsymbol{(1-d)\left(v_i X_i(t)\right)} & (\textbf{deduction}) \end{cases} \tag{6}$$

DIC may liquidate the bank to meet the condition $K(t) = \frac{\frac{\gamma^*}{1+\gamma^*}\sum_{i=1}^{n} Y_i(t)}{(1-\beta)\left(\sum_{i=1}^{n} v_i u_i\right)}$ that maximises the total effect of deposit insurance $\frac{1}{1+x}\sum_{i=1}^{n} P_i$. However, Seta (2021) showed that if for $\overline{K(t)} := \frac{S_0 e^{r^* t}}{(1-\beta)(1+x)}$, the condition $K(t) = \overline{K(t)}$ is met, the bank's risk incentives numerically measured by equation (5) can be resolved regardless of the form of DIS. Hence, by applying this condition to equation (5), we can design the incentive contract for bank's risk incentives even when runs on the bank are likely to occur.

Furthermore, regarding the discounted present value on bank equity $DPV(t,\sigma)$, free cash flow to equity (FCF) $CF(t,\sigma)$, FCF yield $\psi(t,\sigma) := \frac{CF(t,\sigma)}{DPV(t,\sigma)}$ and risk-free rate r_F, the following evaluation of yield spread $\psi(t,\sigma) - r_F$ is obtained using calculation method considering the depositor's behavioural biases if the yield spread is derived from the total bank asset C obtained by equation (5).

$$\boldsymbol{\psi(t,\sigma) - r_F = \frac{1}{t}\left(\ln\sum_{i=1}^{n}(1+x)v_i X_i(t) - \ln\sum_{i=1}^{n} C_i\right)} \tag{7}$$

From the following results of Seta (2021) on the equity risk premium $RP_E(t,\sigma)$ and sustainable growth rate $g(t,\sigma)$, the value of yield spread $\psi(t,\sigma) - r_F$ may function as adjusted equity risk premium for positive values and as bank's credit spread for negative values representing sustainable growth rate.

$$\boldsymbol{\psi(t,\sigma) - r_F = RP_E(t,\sigma) - g(t,\sigma)} \tag{8}$$

4. ANALYSIS OF BANK'S RISK INCENTIVE PROBLEMS BY NUMERICAL SIMULATION ASSUMING OVERLY DEFENSIVE DEPOSIT WITHDRAWALS

This section analyses the impact of banking risk incentives using numerical simulation results assuming overly defensive deposit withdrawals. This is because of the following

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undesired reason: analysis using the actual data of depositors' trends reveals that providing personal information even for research purposes may adversely affect depositors' trusts in bank and give some bias in depositors' trends. We are worried that the discrepancy between the analysis results based on the actual data and the results using depositors' trends, including biases, may hinder accurate verification. Therefore, the numerical simulation fully accomplishes our purpose that the bank's risk incentive problem will occur and the bank's risk incentives can be numerically measured even in situations involving withdrawals of only the amount not covered by DIS and overly defensive deposit withdrawals by depositors sceptical of this system itself. Furthermore, the maximum insurance coverage limit is adopted in the actual DIS in Japan. However, to simplify the depositor's behaviour of withdrawing the remaining amount uncovered by the deposit insurance, we perform numerical simulation assuming fixed-ratio deposit insurance coverage.

The existence of depositors who are strongly affected by status quo bias should not be excluded, even in situations where the effects of loss aversion bias lead to overdefensive deposit withdrawals. It is not just different that individual values are, but for other reasons as well. For example, as long as the country is functioning, some compensation incurred makes depositors feel relieved, including subsidy payment with the expansion of COVID-19 infection in Japan since 2020. With the accumulation of these, status quo bias may strongly affect them.

The numerical simulation using evaluation formulae (5) and (7) and the data of depositors' trends and deposit distribution helps not only depositors to figure out the formula condition of bank but the bank to select the project with higher sustainable growth rate. Depositors may monitor bank's financial condition through numerical simulation based on the predicted data of depositors' trends and the deposit distribution. Meanwhile, the bank is expected to perform the stable and efficient operation through numerical simulation using closed internal data. We also emphasise that the analysis using numerical simulation itself may help restore market discipline.

We suppose a bank with $n = 100$ depositors invests into a project with an initial value of $S_0 = 100$. First, the parameters other than distributions of depositors' trends and deposits are assumed as follows.

$$\boldsymbol{t = 1.00, r - r^{*} = 0.05, \sigma = 0.20 \; or \; 0.40, x = 0.25, \alpha = 0.10, \beta = 0.05} \quad (9)$$

Thus, about 25 percent of the total deposit amount are used for capital increase, and $\sigma = 0.20$ is selected as low risk and $\sigma = 0.40$ as high risk within the range normally used. The deposit spread $r - r^{*} = 0.05$ earns liquidation cost $\alpha = 0.10$ that is higher than the bank's liquidation cost $\beta = 0.05$. Furthermore, the deposit distribution is composed of random numbers that follow a normal distribution with a mean of 1.02 and a variance of 0.03.

Second, by focussing on the value taken by value function as the ratio of withdrawal or deposit amount to the current deposit amount, we can provide the numerical simulation data on deposit trends of depositor A_i $(i = 1, \cdots, 100)$. Given that his/her values are different for each of 100 depositors, the value taken by value function is expressed as uniform random numbers within interval $\left[v^{(i)}{}_{min}, v^{(i)}{}_{max}\right]$, and the probability of withdrawal or deposit is represented as uniform random numbers within interval $\left[p^{(i)}{}_{min}, p^{(i)}{}_{max}\right]$. Under the deposit insurance coverage of 80 or 40 percent, the data for numerical simulation on depositorA_i's deposit trends are provided in the tables below. Notice that each value of value function and the probability of withdrawal or deposit from e_{10} to e_{24} when $a = 0.40$ is the same as $a = 0.80$.

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Table. 1 Deposit trends of depositor A_i $(a = 0.80)$

	e_1	e_2	e_3	e_4	e_5	e_6	e_7	e_8
$v^{(i)}{}_{min}$	-0.94	-0.84	-0.74	-0.64	-0.54	-0.44	-0.34	-0.24
$v^{(i)}{}_{max}$	-0.86	-0.76	-0.66	-0.56	-0.46	-0.36	-0.26	-0.16
$p^{(i)}{}_{min}$	0.01148	0.00756	0.00468	0.00322	0.00651	0.0140	0.0543	0.7611
$p^{(i)}{}_{max}$	0.01150	0.00758	0.00470	0.00324	0.00653	0.0142	0.0545	0.7613
	e_9	e_{10}	e_{11}	e_{12}	e_{13}	e_{14}	e_{15}	e_{16}
$v^{(i)}{}_{min}$	-0.14	0.006	0.016	0.026	0.036	0.046	0.056	0.066
$v^{(i)}{}_{max}$	-0.06	0.014	0.024	0.034	0.044	0.054	0.064	0.074
$p^{(i)}{}_{min}$	0.0372	0.012	0.0185	0.0225	0.0185	0.012	0.0075	0.0035
$p^{(i)}{}_{max}$	0.0374	0.014	0.0187	0.0227	0.0187	0.014	0.0077	0.0037
	e_{17}	e_{18}	e_{19}	e_{20}	e_{21}	e_{22}	e_{23}	e_{24}
$v^{(i)}{}_{min}$	0.076	0.086	0.096	0.106	0.296	0.506	0.696	0.906
$v^{(i)}{}_{max}$	0.084	0.094	0.104	0.294	0.504	0.694	0.904	0.994
$p^{(i)}{}_{min}$	0.0013	0.0005	0.00019	0.00009	0.00007	0.00005	0.00003	0.00001
$p^{(i)}{}_{max}$	0.0015	0.0007	0.00021	0.00011	0.00009	0.00007	0.00005	0.00003

Table. 2 Deposit trends of depositor A_i $(a = 0.40)$

	e_1	e_2	e_3	e_4	e_5
$v^{(i)}{}_{min}$	-0.94	-0.84	-0.74	-0.64	-0.54
$v^{(i)}{}_{max}$	-0.86	-0.76	-0.66	-0.56	-0.46
$p^{(i)}{}_{min}$	0.38884	0.2350	0.03211	0.24120	0.00246
$p^{(i)}{}_{max}$	0.38886	0.2352	0.03213	0.24122	0.00248
	e_6	e_7	e_8	e_9	
$v^{(i)}{}_{min}$	-0.44	-0.34	-0.24	-0.14	
$v^{(i)}{}_{max}$	-0.36	-0.26	-0.16	-0.06	
$p^{(i)}{}_{min}$	0.00071	0.000024	0.0000044	0.0000004	
$p^{(i)}{}_{max}$	0.00073	0.000026	0.0000046	0.0000006	

Furthermore, the deposit trends are generated as uniform random numbers so as to satisfy $v^{(i)}(e_1) \leq \cdots \leq v^{(i)}(e_9) \leq 0 \leq v^{(i)}(e_{10}) \leq \cdots \leq v^{(i)}(e_{24})$. Regarding probability $p_j{}^{(i)}$ that e_j occurs, intervals $[p^{(i)}{}_{min}, p^{(i)}{}_{max}]$ are adjusted so that the difference between depositors' trends is not noticeable. Certainly, the cause of withdrawal or deposit varies from one depositor to another depositor. However, the reason is that depositors are already categorised according to the ratio of withdrawal or deposit amount to current deposit amount.

Each value in the tables explains the assumptions about depositors' deposit trends. In Table. 1, $p^{(i)}{}_{max}$ is the largest at 0.7613, whereas $v^{(i)}{}_{min}$ and $v^{(i)}{}_{max}$ are -0.24

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and -0.16, and hence, the deposit insurance with 80 percent coverage implies that most depositors will withdraw the remaining 20 percent. If depositors think that compensation will not occur under the DIS; their behaviours of withdrawing deposits are considered as the increase in ${p^{(i)}}_{min}$ and ${p^{(i)}}_{max}$ when ${v^{(i)}}_{max}$ is -0.66 or less. However, ${p^{(i)}}_{max}$ in Table. 2 is maximised in the case of e_1. This reflects the situation where, recognising that the deposits will be not protected under the DIS, many depositors withdraw their deposits. Setting the interval $[{p^{(i)}}_{min}, {p^{(i)}}_{max}]$ to $[0.24120, 0.24122]$, when ${v^{(i)}}_{min}$ and ${v^{(i)}}_{max}$ are -0.64 and -0.56, respectively, represents deposit trends of some depositors who withdraw only the remaining uncompensated amount in the hope that their own deposit will be completely protected under any circumstances. Additionally, Table. 1 shows that the phenomenon of low frequency ${p^{(i)}}_{max}$, when ${v^{(i)}}_{min}$ is positive, and the effects of status quo bias may prompt depositors to make more deposits.

Following Tversky and Kahneman (1992), we generated the parameters γ^- or γ^+ used in probability weighting function for each depositor as random numbers that follow uniform distribution within each interval $[0.685, 0.695]$ or $[0.605, 0.615]$. These parameters imply that when the cumulative probability is low, the loss aversion bias works and loss situation is overestimated, whereas when its probability is high, the status quo bias works, and gain situation is underestimated. In depositors' deposit trends set from Table. 1 and Table. 2, the prospect values for each depositor are evaluated to be about 0.8 and about 0.4, respectively. Therefore, the results of $a = 0.80$ and $a = 0.40$ in Seta and Inoue (2020) and Seta (2021) can also be applied to situations where overly defensive deposit withdrawals occur, as shown in Table. 1 and Table. 2.

Numerical simulation assuming depositors' deposit trends, including overly defensive deposit withdrawals, provides three types of graphs as numerical examples explaining the impact of bank's risk incentives. Each graph for each volatility σ on bank's risk incentives, probability of DIC's liquidation and bank's credit spread will expound the occurrence and the impact of bank's risk incentives. Furthermore, the bank's risk incentive problem in situations where bank runs are occurring or likely to occur will be discussed in depositors' deposit trends, especially from the perspectives of loss aversion bias and status quo bias.

i) Bank's risk incentives

Seta and Inoue (2020) emphasised that banks' risk incentives are classified into two types: risk incentive for depositors and bank's shareholders. The risk incentive for bank's shareholders drawn on the graph as a negative value can be interpreted as a normal borrower's risk incentive by inverting negative values to positive values. To analyse the situation in which bank's risk incentives may occur, we assume that, without using incentive contracts, DIC would liquidate the bank at knockout price to maximise the total effect of deposit insurance. Therefore, for $a = 0.80$ and $a = 0.40$, DIC will liquidate bank at 60.75 or 30.38 in Figure. 1 or at 32.71 or 16.36 in Figure. 2, respectively.

The graph of the bank's risk incentive consists of value of invested project S on horizontal axis and numerically measured value of bank's risk incentives on the vertical axis, which expresses as an increment in total bank equity when volatility σ increases by 1 percent. The comparison between Figure. 1 and Figure. 2 provides the situation that the bank switches from the invested project with $\sigma = 0.20$ to the one with $\sigma = 0.40$. The same comparison of switches of the invested

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project is also used to graph the probability of DIC's liquidation and bank's credit spread.

Regardless of volatility σ, the absolute value of the bank's risk incentive for depositors is higher at $a = 0.40$ than at $a = 0.80$ when the project value is low. Overly defensive deposit withdrawal occurs more frequently, and loss aversion bias incurs an overestimation of loss situation. Consequently, the value of the probability weighting function increases. In this situation, the bank worries about bank runs and rush business recovery, making depositors aware of the occurrence of bank runs. Thus, the bank's risk incentive for depositors will militate against the bank. Regarding the reason why bank's risk incentive for bank's shareholders does not occur when the project does not get worse at $a = 0.40$ than at $a = 0.80$, it may apply to the situation where the bank make effort to recover its performance by switching to highly risky project before bank runs occurs. Therefore, bank runs are treated as a factor in the occurrence of bank's risk incentive for depositors.

When volatility σ is equal to 0.40, the phenomenon that bank's risk incentive for depositors continue to increase, which is also known as chronic risk incentive, is observed. Given the result that not only numerically measured value of bank's risk incentive for depositors is larger at $a = 0.80$ than at $a = 0.40$, but also profit situation incurred by a status quo bias is underestimated, deposit protection by the DIS may affect the chronicity of bank's risk incentive for depositors.

ii) Probability of DIC's liquidation

Next, the situation in which the incentive contract applies is also included in the comparison. Both Figure. 3 and Figure. 4 show that the bank liquidating probability by DIC increases when DIC liquidated the bank by using the incentive contract. Considering the case where incentive contract is not enforced, when the invested project gets worse, the delay in bank liquidation by DIC may be a factor that prompts the bank to generate bank's risk incentives.

Regarding the low probability of DIC's liquidation at $a = 0.40$, delays in DIC's liquidation may not be a problem for DIC under policy that DIC prioritises increasing the effectiveness of deposit insurance. Certainly, early bank liquidation and deposit compensation may be required in a situation where bank runs are occurring or likely to occur, but the graphs of probability of DIC's liquidation show that prioritising maximisation of the total effect of deposit insurance may cause DIC to select liquidation delay even in such situations. If overly defensive withdrawals could lead to bank runs, maximising the overall effect of deposit insurance would also incur delay in bank liquidation by DIC and cause to ferment bank's risk incentives.

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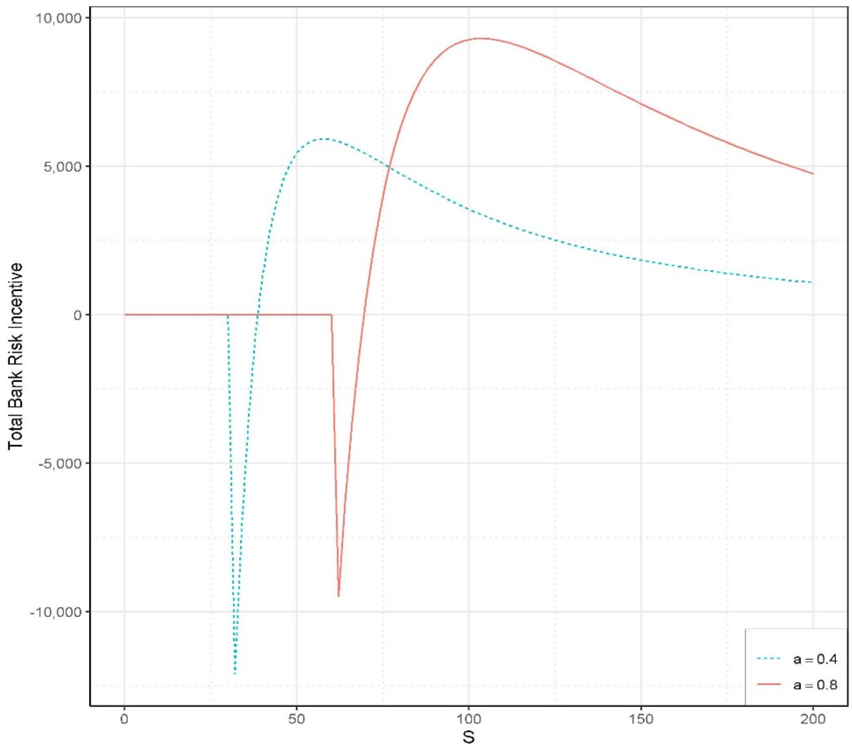

Figure. 1 Total risk incentives ($\sigma = 0.20$).

Table. 3 Total risk incentives ($\boldsymbol{\sigma = 0.20}$).

$\boldsymbol{S}$	20	40	60	80	100	120
$\boldsymbol{a = 0.4}$	0.0000	1297.8533	5899.3286	4750.0012	3552.1210	2683.3219
$\boldsymbol{a = 0.8}$	0.0000	0.0000	0.0000	6292.4193	9268.4411	8810.6422

Applying incentive contracts may force DIC to switch from maximising the total effect of deposit insurance to early bank liquidation. However, when depositors overestimate loss situation with loss aversion bias, early bank liquidation will lead to bank runs. Thus, establishing a reliable DIS with a high compensation rate and implementing an incentive contract may be necessary to prevent bank runs and mitigate or resolve the bank's risk incentives.

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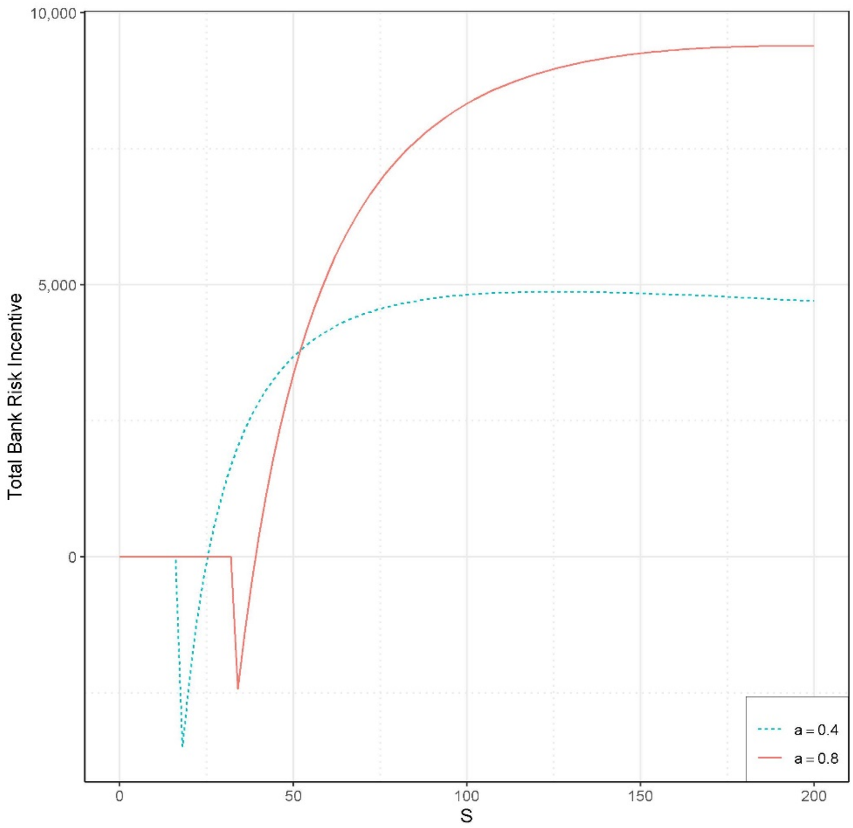

Figure. 2 Total risk incentives ($\boldsymbol{\sigma = 0.40}$).

Table. 4 Total risk incentives ($\boldsymbol{\sigma = 0.40}$).

$\boldsymbol{S}$	**20**	**40**	**60**	**80**	**100**	**120**
$\boldsymbol{a = 0.4}$	-2255.4480	2845.8250	4164.8107	4638.8775	4817.2682	4868.7757
$\boldsymbol{a = 0.8}$	0.0000	366.1095	5230.4307	7301.6036	8329.2332	8874.3680

iii) Bank's credit spread

Equations (5) and (7) remind us that when incentive contract is enforced, total bank equity can be evaluated without being influenced by the form of DIS and that the value of bank's credit spread is irrelevant to depositors' deposit trends. Due to the effect of incentive contract, the numerically measured value of bank's risk incentives will be 0, and hence, the evaluated value of total bank equity does not fluctuate depending on the project risk. Then, bank's credit spread with zero value means that the equity risk premium and the sustainable growth rate are offset.

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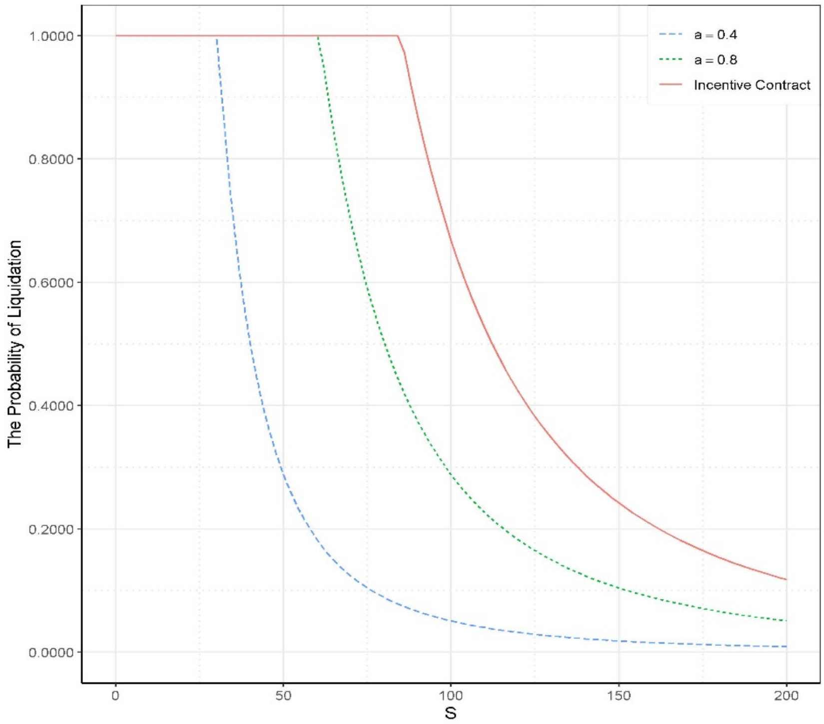

Figure. 3 The probability of DIC's liquidation ($\boldsymbol{\sigma = 0.20}$).

Table. 5 The probability of DIC's liquidation ($\boldsymbol{\sigma = 0.20}$).

$\boldsymbol{S}$	**20**	**40**	**60**	**80**	**100**
$\boldsymbol{a = 0.4}$	1.0000	0.5026	0.1824	0.0888	0.0509
$\boldsymbol{a = 0.8}$	1.0000	1.0000	1.0000	0.5026	0.2877
Incentive Contract	1.0000	1.0000	1.0000	1.0000	0.6672
$\boldsymbol{S}$	120	140	160	180	200
$\boldsymbol{a = 0.4}$	0.0322	0.0219	0.0157	0.0117	0.0090
$\boldsymbol{a = 0.8}$	0.1824	0.1241	0.0888	0.0662	0.0509
Incentive Contract	0.4230	0.2877	0.2061	0.1535	0.1180

It is recognised by equation (8) that equity risk premium or sustainable growth rate is depicted from the graph of bank credit spread as positive or negative value, respectively. However, considering the equity risk premium and sustainable growth rate cancel each other out, these observed values may be underestimated. Nevertheless, analysing the impact of bank's risk incentives on the equity risk premium and sustainable growth rate will be sufficiently attained.

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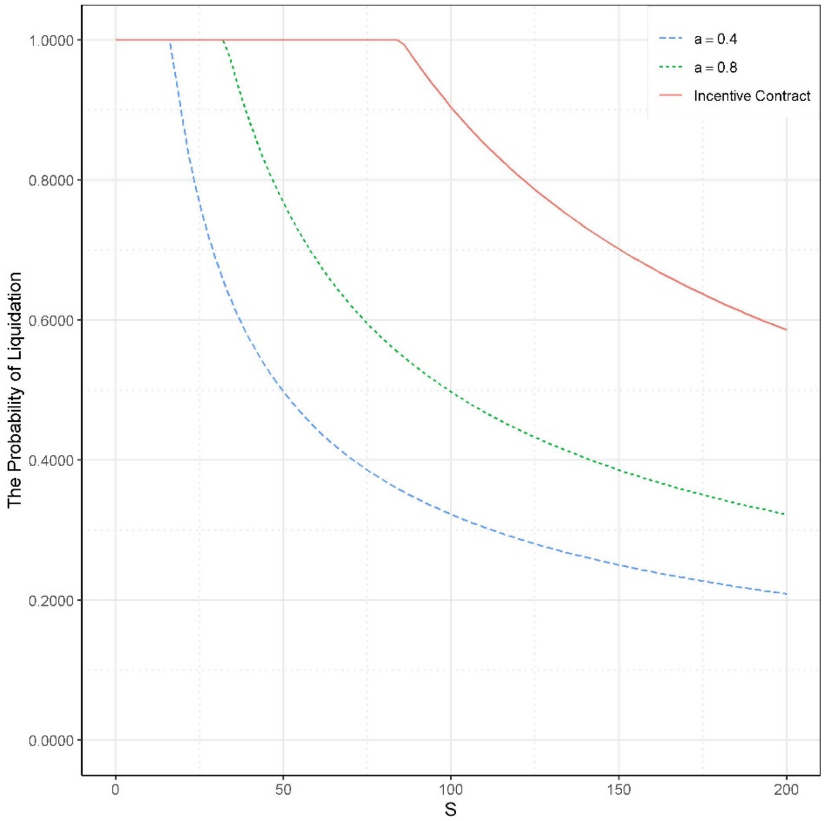

Figure. 4 The probability of DIC's liquidation ($\boldsymbol{\sigma = 0.40}$).

Table. 6 The probability of DIC's liquidation ($\boldsymbol{\sigma = 0.40}$).

$\boldsymbol{S}$	**20**	**40**	**60**	**80**	**100**
$\boldsymbol{a = 0.4}$	0.8819	0.5718	0.4438	0.3708	0.3225
$\boldsymbol{a = 0.8}$	1.0000	0.8819	0.6845	0.5718	0.4974
Incentive Contract	1.0000	1.0000	1.0000	1.0000	0.9038
$\boldsymbol{S}$	120	140	160	180	200
$\boldsymbol{a = 0.4}$	0.2878	0.2614	0.2404	0.2234	0.2091
$\boldsymbol{a = 0.8}$	0.4438	0.4031	0.3708	0.3445	0.3225
Incentive Contract	0.8065	0.7324	0.6737	0.6259	0.5860

When the project value is greater than the initial value, a sustainable growth rate is observed, and by contrast, the equity risk premium is observed. Based on the value of the bank's credit spread and under the situation that the incentive contract applies, which is irrelevant to changes in the project volatility, switching to a project with higher volatility reduces the equity risk premium and increases the sustainable growth rate. In comparison with the situation where bank's risk incentives occur, if the numerically measured value of bank's risk incentive is zero, the reduction of equity risk premium is confirmed to the extent that is offset by sustainable growth rate. Therefore, the bank's risk incentives may increase equity risk premium.

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At $a = 0.40$, the probability of overly defensive deposit withdrawal is higher, and loss situation may be overestimated by loss aversion bias. Then, the equity risk premium indicates larger value. Thus, bank runs caused by the impact of bank's risk incentives may also be related to the increased equity risk premium.

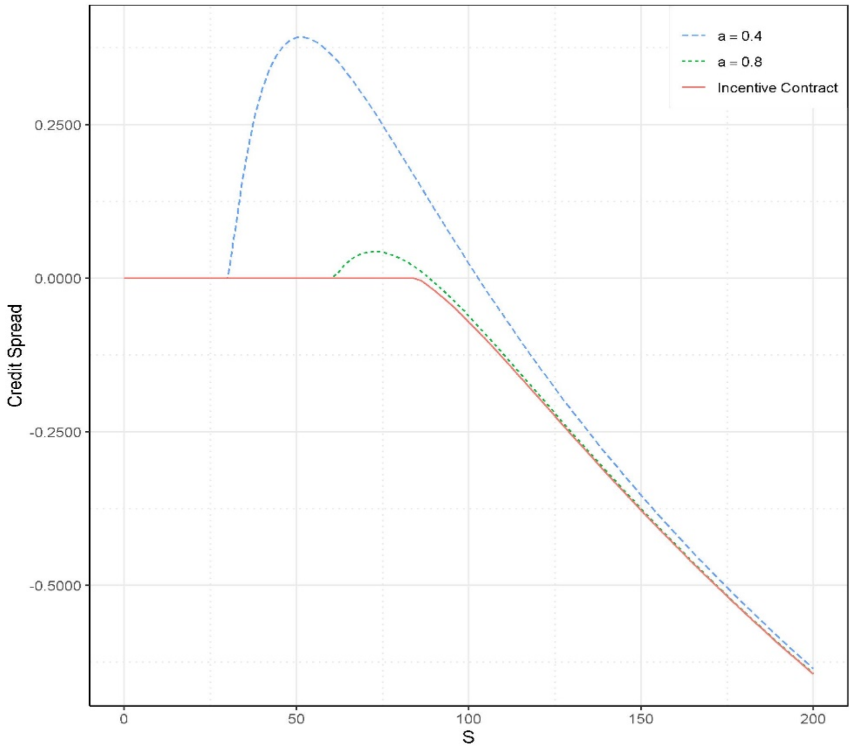

Figure. 5 Bank's credit spread ($\boldsymbol{\sigma = 0.20}$).

Table. 7 Bank's credit spread ($\boldsymbol{\sigma = 0.20}$).

$\boldsymbol{S}$	**20**	**40**	**60**	**80**	**100**	**120**
$\boldsymbol{a = 0.4}$	0.0000	0.3076	0.3644	0.2035	0.0234	-0.1412
$\boldsymbol{a = 0.8}$	0.0000	0.0000	0.0000	0.0327	-0.0619	-0.1880
Incentive Contract	0.0000	0.0000	0.0000	0.0000	-0.0714	-0.1933

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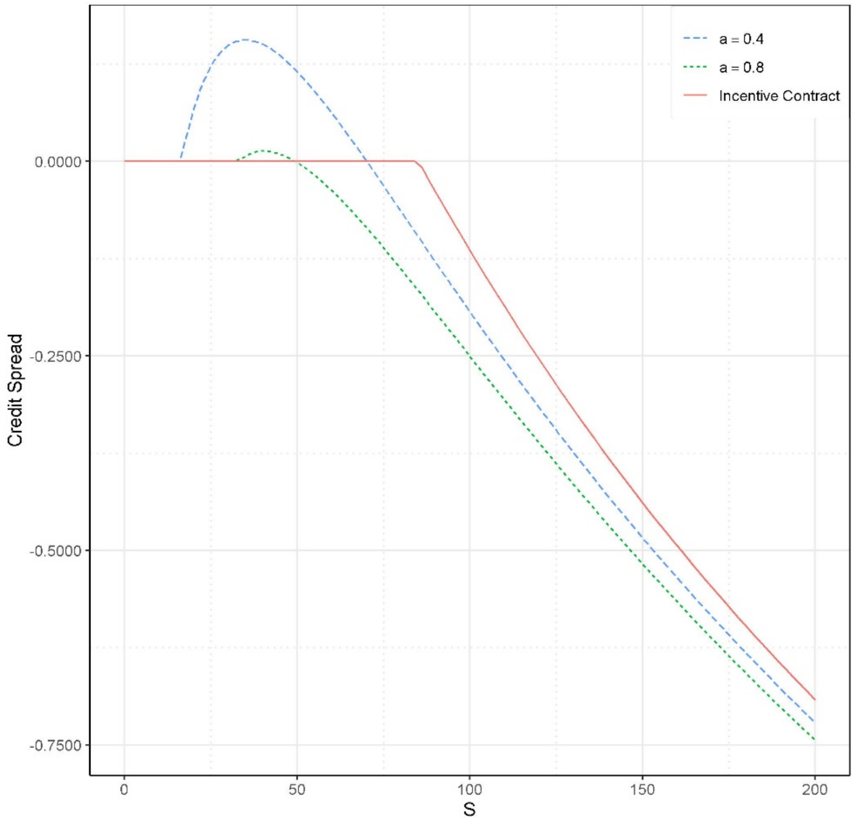

Figure. 6 Bank's credit spread ($\boldsymbol{\sigma = 0.40}$).

Table. 8 Bank's credit spread ($\boldsymbol{\sigma = 0.40}$).

$\boldsymbol{S}$	**20**	**40**	**60**	**80**	**100**	**120**
$\boldsymbol{a = 0.4}$	0.0679	0.1507	0.0620	-0.0641	-0.1935	-0.3164
$\boldsymbol{a = 0.8}$	0.0000	0.0133	-0.0375	-0.1383	-0.2507	-0.3618
Incentive Contract	0.0000	0.0000	0.0000	0.0000	-0.1145	-0.2546

5. CONCLUSION

Under the circumstances where depositors sceptical of DIS itself overdefensively withdrew their deposits and where bank runs were likely to be caused, this study argued the bank's risk incentive problem from the perspective of behavioural biases: loss aversion bias and status quo bias. When such situations would cause the bank liquidation by DIC, bank's endogenous bankruptcy, or an injection of taxpayers' money, we analysed the impact of bank's risk incentives considering Japanese depositors' behavioural biases by focusing on the bank liquidation by DIC. After reflecting such a situation in Japanese depositors' deposit trends, this study performed numerical simulations by evaluating cumulative prospect theory Choquet integral. Consequently, the bank's risk incentive problem was observed along with the numerical measurement of bank's risk incentives. Additionally, if DIC took the policy of maximising the total effect of deposit insurance, even when the invested project worsened, DIC would leave

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the bank's risk incentives, thereby causing the bank to behave riskily by delaying the bank liquidation.

When the bank's financial condition deteriorates, overestimation of the loss situation due to loss aversion bias may give depositors a more suspicious view about deposit compensation under the DIS; consequently, it may lead to overly defensive deposit withdrawals. Given that underestimating profit situation by status quo bias will make depositors treat their deposits like risk-free assets, leaving deposits in banks may lead to loosening depositors' monitoring of bank. Then, by the cumulative prospect theory Choquet integral whose integrand is equivalent to the value function that takes each ratio of withdrawal amount or deposit amount to current deposited amount, the depositors' behavioural biases in such situations can be evaluated as a prospect value for each depositor. The probability weighting function reflecting the effects of loss aversion bias and the status quo bias may also imply the existence of deposit trend distribution that includes extremely biased behaviours of depositors placed in such as financial crisis or lockdown.

The prospect values on depositors' deposit trends were incorporated into analytical valuation formulae, which Seta and Inoue (2020) and Seta (2021) developed with option pricing theory, to evaluate the total bank equity and bank's credit spreads and numerically measure bank's risk incentives. It enables us to proceed with numerical simulation and analysis focusing on Japanese depositors' behaviours, such as withdrawal and deposit. The numerical simulations assume that some Japanese depositors overdefensively withdraw their deposits and bank runs are occurring or likely to occur. These simulations can explain that such behaviour of Japanese depositors raises concerns about bank runs to the bank and causes bank's risk incentive problem to recover business performance. Consequently, if bank runs become more realistic, the bank's risk incentives may affect the increase in equity risk premium by overestimating depositors' losses caused by loss aversion bias.

The occurrence of bank runs may lead to bankruptcy due to the bank's endogenous factors as well as DIC's bank liquidation. Then, depositors' deposit trends will affect the occurrence of bank runs and bank's risk incentives. Therefore, it is more advisable to clarify the process of occurrence of bank's risk incentive problem and the impact of bank's risk incentives, analysing depositors' deposit trends that assume the relevant situations as much as possible.

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