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Automating Collateral Management in Securities Lending: A Blockchain Approach

Hironori MATSUSHITA[a,1], Kento MARUOKA[a], Yutaka OKADA[b], Kenji ISIYAMA[b] and Kenji TANAKA[a]
[a]*University of Tokyo, Japan*
[b] *Japan Securities and Finance Company, Japan.*

Abstract. The financial market stress of 2008, triggered by the collapse of Lehman Brothers, underscored the critical need for efficient collateral management in financial transactions. This research focuses on developing and simulating a blockchain platform designed to automate the collateral value adjustment in securities lending transactions, where the key stakeholders include financial institutions, market participants, and regulatory bodies. The platform proposes innovative transaction flows and algorithms to manage collateral automatically, significantly making risk management more effective and reducing administrative costs. The study's methodology includes 1) designing a blockchain platform for automated collateral management, 2) developing and testing collateral value adjustment algorithms, and 3) conducting case studies with real stock and bond price data to evaluate the platform's effectiveness. A notable outcome of this research is the reduced credit risk and liquidity compared to traditional procedures, based on the benefit of collateral diversification enabled by the automated algorithms employing multiple tokens as collaterals. This research contributes to the field of transdisciplinary engineering by integrating financial and technological disciplines, particularly in leveraging blockchain technology for financial applications. Furthermore, the study reflects on broader societal impacts, such as improving the efficiency and security of financial transactions, potentially stabilizing market volatility, and offering insights for policy-making in sound and robust settlement systems.

Keywords. Blockchain, Financial Transactions, Collateral Management, Risk Reduction, Transdisciplinary Engineering.

Introduction

In the aftermath of the 2008 global financial crisis, the importance of effective collateral management in securities lending and repo transactions has come to the forefront. The crisis exposed the vulnerabilities of the existing collateral management infrastructure, highlighting the need for more robust and efficient systems to mitigate counterparty risk and ensure financial stability. Regulatory initiatives, such as Basel III, have introduced stricter capital requirements for financial institutions, leading to an increased demand for collateral globally. While these regulations do not directly dictate collateral management

[1] Corresponding Author, Email: hironori-matsushita@g.ecc.u-tokyo.ac.jp.

practices, they have highlighted the need for more efficient and effective collateral management systems to meet the growing demand.

However, traditional collateral management processes often involve manual interventions, leading to operational inefficiencies, increased costs, and heightened risk exposure. The lack of automation and standardization in these processes hinders the ability of financial institutions to respond quickly to market changes and regulatory requirements. Moreover, the fragmented infrastructure and reliance on bilateral agreements expose participants to counterparty risk, as evidenced by the collapse of Lehman Brothers during the crisis.

1. Background and Motivation

1.1. Challenges in Collateral Management

The domain of collateral management has undergone significant transformation, particularly in the wake of heightened regulatory scrutiny and evolving market demands. A recent study delves into the global trends and challenges of collateral management, underscoring the shifting role of collateral across the banking sector and fintech innovations [1]. These developments have brought about a paradigm shift, compelling financial institutions to navigate a complex landscape marked by operational inefficiencies, fragmented systems, and increased counterparty risk. The challenges are multifaceted, ranging from the need for efficient collateral utilization to compliance with stringent regulatory frameworks, all of which contribute to elevated operational costs and impinge on the profitability of market participants [2].

1.2. Blockchain Technology in Finance

Blockchain technology has emerged as a transformative force in finance, offering a suite of features that could potentially revolutionize traditional financial processes, including collateral management. Its decentralized nature, coupled with the immutability and transparency of transactions, positions blockchain as a promising solution to the inefficiencies plaguing current financial systems [3].

In the context of collateral management, blockchain technology can offer several benefits, such as automated collateral processes, real-time transparency, efficient collateral allocation, reduced counterparty risk, and increased interoperability [4]. Smart contracts and tokenization on blockchain platforms enable the automation of complex financial transactions, reducing the need for intermediaries and improving efficiency [5].

1.3. Previous Studies and Research Gap

Previous studies have explored the application of distributed ledger technology (DLT) in collateral management. Priem [6] discussed the potential of DLT to reduce costs associated with clearing processes and noted that the reduction of administrative costs could lead to faster collateral value adjustment processing. Morini [7] emphasized the benefits of more accurate collateral value clearing and the potential for collateral adjustments to be executed within an hour using DLT.

Karaivanov [8] proposed a transaction algorithm that leverages the advantages of blockchain while reducing collateral costs. The Deutsche Börse Group and the Deutsche Bundesbank's "Blockbaster" project [4] investigated the potential impact of DLT on collateral management, suggesting that introducing DLT in parallel with existing systems, complementing them, is more realistic when considering legal regulations and management policies.

However, there is a lack of comprehensive studies that develop and evaluate a blockchain-based platform for automating collateral management in securities lending transactions. Additionally, the compatibility of blockchain-based solutions with existing regulations and legal requirements remains a significant hurdle that needs to be addressed. While some studies, such as the one by the Deutsche Bundesbank, have proposed collateral management systems that consider current legal regulations, there is still a lack of research on verifying how these methods can effectively reduce price fluctuation risk and on systems that align with Japan's current system.

1.4. Research Objectives and Contributions

This research aims to address the challenges associated with traditional collateral management processes by developing and evaluating a blockchain-based platform for automating collateral management in securities lending transactions. The proposed platform leverages smart contracts and tokenization to streamline the collateral management process, reduce operational risks, and improve efficiency.

The main contributions of this research include:

1. Designing a blockchain platform that enables the tokenization of assets and automates the margin call process using smart contracts.
2. Developing and implementing collateral value adjustment algorithms for single-token and multi-token scenarios.
3. Conducting simulations using historical market data to evaluate the platform's performance under different market conditions.
4. Analyzing the implications of the proposed platform for collateral management and identifying potential challenges and future research directions.

By addressing the challenges in collateral management and exploring the potential of blockchain technology, this research contributes to the growing body of knowledge on the application of blockchain in the financial sector. The findings and insights from this study can inform future research and development efforts in the area of blockchain-based financial solutions, while also providing valuable insights for practitioners and policymakers. Thus, this research highlights the transdisciplinary nature of the problem, bridging finance, engineering, and technology to address the complex challenges in collateral management and drive innovation in the financial industry.

2. Methodology

2.1. Blockchain Platform Design

2.1.1. Tokenization and Transaction Flow

The proposed blockchain platform leverages the Ethereum blockchain and its smart contract functionality to automate collateral management in securities lending transactions. The platform revolves around the tokenization of assets, where securities and cash collateral are represented as digital tokens on the blockchain. This enables efficient transfer and management of collateral throughout the transaction lifecycle. The transaction flow on the platform consists of the following key steps:

1. Token Issuance: Participants deposit their assets (securities or cash) with a trusted third party, which issues corresponding tokens on the blockchain.
2. Transaction Initiation: The lender and borrower agree on the terms of the transaction, and the lender transfers loan tokens to the borrower, while the borrower transfers collateral tokens to the lender.
3. Margin Maintenance: The platform performs daily mark-to-market valuations of the collateral and loan tokens, triggering margin calls if the collateral value falls below a predefined threshold.
4. Transaction Settlement: At the end of the transaction, the borrower returns the loan tokens to the lender, and the lender returns the collateral tokens to the borrower.

Note that the requirement for additional issuance is anticipated in advance in this study. Consequently, the simulation is predicated on the assumption that the borrower has proactively issued and possesses an adequate quantity of tokens in their account for the purpose of collateral value adjustment.

This approach enables a comprehensive evaluation of the outcomes derived from fully leveraging the automated value adjustment feature inherent in the proposed methodology. The tokenization of assets and the use of smart contracts streamline the collateral management process, reducing manual interventions and enabling real-time updates.

2.1.2. Margin Call Mechanism

The margin call mechanism is a critical component of the platform, ensuring that the collateral value is maintained above a predefined threshold throughout the transaction lifecycle. The mechanism is automated using smart contracts and follows these steps:

1. Valuation: The platform retrieves the current market prices of the collateral and loan tokens from trusted oracles.
2. Threshold Calculation: The collateral-to-loan ratio is calculated based on the predefined haircut rate α and margin call threshold β. The haircut rate α, set to 0.05, acts as a protective measure for the lender against the risk of the collateral's value declining. Meanwhile, the margin call threshold β, set to 0.02, indicates the point at which additional collateral or repayment is required to maintain the loan's terms.
3. Margin Call Trigger: If the collateral-to-loan ratio falls below the margin call threshold β, a margin call is automatically triggered.
4. Collateral Top-up: The borrower is notified to provide additional collateral tokens within a specified timeframe to restore the required ratio.
5. The automated margin call mechanism helps mitigate counterparty risk and ensures the adequate collateralization of the loan throughout the transaction.

2.2. Collateral Value Adjustment Algorithms

2.2.1. Single-Token Algorithm

The single-token adjustment algorithm is designed to handle collateral value adjustments using a single designated collateral token. The algorithm follows these steps:

1. Calculate the total collateral value ($total\_price_{CT}$) and total loan value ($total\_price_{ST}$) using the following equations:

$$total\_price_{CT} = \sum_{i} P_{CT\,i} N_{CT\,i}$$

$$total\_price_{ST} = \sum_{j} P_{St\,j} N_{ST\,j}$$

   where $P_{CT\,i}$ and $N_{CT\,i}$ are the price and quantity of the ith collateral token CT_i, and $P_{ST\,j}$ and $N_{ST\,j}$ are the price and quantity of the jth security token ST_j.
2. Compare the collateral value to the loan value multiplied by the haircut rate α using the following equation:

$$(1-\alpha) total\_price_{CT} \geq total\_price_{ST}$$

3. If the collateral value is less than the adjusted loan value, calculate the required additional collateral tokens and transfer them from the borrower to the lender.
4. If the collateral value is greater than the adjusted loan value, calculate the excess collateral tokens and transfer them from the lender to the borrower.

The single-token adjustment algorithm provides a straightforward approach to maintaining the required collateral-to-loan ratio.

2.2.2. Multi-Token Algorithm

The multi-token adjustment algorithm extends the single-token approach by utilizing multiple collateral tokens for value adjustment based on a predefined priority order, CT_1 to CT_n in order of priority. The algorithm follows similar steps as the single-token adjustment, but with the additional consideration of the priority order when transferring collateral tokens. When adjusting the collateral value, the algorithm follows these rules:

- If additional collateral is needed,
  - the collateral tokens will be transferred from the borrower to the lender in the order(CT_1 to CT_5) until the required collateral value is reached;
  - if the borrower does not have sufficient collateral tokens, additional tokens will be issued to meet the required value.
- If the collateral value needs to be returned;
  - the collateral tokens will be returned from the lender to the borrower in the reverse order (CT_5 to CT_1) until the desired collateral value is achieved;
  - if the lender does not have sufficient collateral tokens to return, the remaining tokens will be returned as available.

2.3. Simulation Model and Case Studies

2.3.1. Simulation Setup and Parameters

The simulations are conducted using a custom-built simulator that replicates the proposed blockchain platform's functionality. The simulator is designed to process historical stock price data and execute collateral management algorithms based on predefined parameters. The historical stock price data were obtained from a library called yfinance. The following parameters are consistent across all simulation models.

1. Haircut rate (α): Set to 0.05, representing a 5% reduction in the assessed value of the collateral relative to its market value.
2. Margin call threshold (β): Set to 0 or 0.02, representing a 2% buffer between the collateral and loan values. Note that the collateral value is calculated from the haircut rate.
3. Collateral adjustment frequency: Daily, based on the closing prices of the underlying assets.
4. Simulation period: Each case study covers a two-month period (62 days), considering both trading and non-trading days.

The simulations use a representative portfolio of stocks commonly used as collateral in the Japanese stock lending market. The collateral portfolio consists of the following assets for 1,000,000 stocks each.

- $CT^{8306}(= CT_1)$: 8306 (Mitsubishi UFJ Financial Group, Inc.)
- $CT^{8604}(= CT_2)$: 8604 (Nomura Holdings, Inc.)
- $CT^{4901}(= CT_3)$: 4901 (FUJIFILM Holdings Corporation)
- $CT^{7013}(= CT_4)$: 7013 (IHI Corporation)
- $CT^{8031}(= CT_5)$: 8031 (MITSUI & CO., LTD.)

The loan asset (also described as security token ST) is a cash equivalent (Japanese yen) with a value equal to the initial collateral value calculated by the haircut and the total collateral value.

2.3.2. Simulation Models

Five simulation models, shown in Table 1, are employed to evaluate the proposed platform's performance and compare it with current collateral management practices. Note that Model 0 replicates the current collateral management process using a third-party clearing house (JSCC). Margin calls are triggered daily, but the adjustment is executed with a one-day lag. This model serves as a benchmark for comparison with the proposed blockchain-based models.

Table 1. Simulation Models

Models	**β (Threshold for Margin Call)**	**Token Adjustment**	**Immediate Token Transfer**
Model 0	0	Single	×
Model 1	0	Single	○
Model 2	0	Multiple	○
Model 3	0.02	Single	○
Model 4	0.02	Multiple	○

2.3.3. Case Studies

The simulations are conducted under four different market scenarios to assess the performance of the proposed platform and algorithms under varying conditions, as shown in Table 2. Each case study covers a two-month period within the 2008-2009 timeframe, capturing different market dynamics related to the global financial crisis.

1. Case Study 1 (Normal Market): Represents a period of relatively stable market conditions from July 1, 2009, to August 31, 2009.

2. Case Study 2 (Market Crash): Represents a period of significant market decline from October 1, 2008, to December 1, 2008, capturing the initial impact of the global financial crisis.
3. Case Study 3 (Market Rally): Represents a period of market recovery from March 1, 2009, to May 1, 2009, following the market crash.
4. Case Study 4 (High Volatility): Represents a period of increased market volatility from November 1, 2008, to January 1, 2009, during the height of the financial crisis.

The case studies provide a comprehensive evaluation of the proposed platform's performance under different market conditions.

Table 2. Portfolio of collateral and loan assets in each case.

Cases	**Collateral (million)**					**Loan assets (yen)**
	CT^{8306}	CT^{8604}	CT^{4901}	CT^{7013}	CT^{8031}	
Case 1	1	1	1	1	1	6,983,450,000
Case 2	1	1	1	1	1	7,595,250,000
Case 3	1	1	1	1	1	4,106,850,000
Case 4	1	1	1	1	1	5,699,050,000

2.3.4. Evaluation Metrics

The performance of the proposed method is evaluated using two key metrics:

1. Price Fluctuation Risk: Measured by the maximum and average difference between the actual collateral value $(1-\alpha)total\_price_{CT}$ and the securities value $total\_price_{ST}$ during the simulation period. The actual collateral and securities values are calculated after each daily margin call execution. In cases where immediate value adjustment is not possible, such as when additional token issuance is required by the lender, the values are calculated before the value adjustment.
2. Operational Costs: Measured by the number of additional token issuances triggered during the simulation period. As mentioned, the borrower is assumed to have a sufficient quantity of value adjustment tokens issued before the start of the transaction, so additional issuances are not triggered for Case Study 1-4, described below, on the borrower side. Therefore, only the cases where additional token issuance is required by the lender are counted.

3. Results and Discussions

3.1. Simulation Results

Tables 3 and 4 show the summary of the simulation results.

The case studies demonstrate the proposed blockchain-based collateral management platform's ability to outperform the current practice (Model 0) in various market conditions. In the normal market scenario (Case Study 1), all proposed models (Models 1-4) significantly reduced the price fluctuation risk and operational costs compared to Model 0. Models 1 and 2 (without margin call threshold) maintained the risk within the token price range since the token is indivisible.

During the market crash scenario (Case Study 2), Models 1 and 2 continued to maintain the risk within the token price range, while Models 3 and 4 (with a 2% margin call threshold) limited the maximum price fluctuation risk to 13% of Model 0 with a less number of margin calls. This highlights the robustness of the proposed models in handling extreme market downturns.

The market rally scenario (Case Study 3) revealed a significant difference between single-token adjustment models (Models 1 and 3) and multi-token adjustment models (Models 2 and 4). Models 1 and 3 faced a risk of price fluctuation similar to that of Model 0. This was due to the collateral value increasing continuously in relation to the loan value. As a result, the lender needed to issue additional tokens multiple times, incurring operational costs. In contrast, Models 2 and 4 effectively managed the risk throughout the market rally and eliminated the need for additional token issuance, demonstrating the advantages of multi-token adjustment in scenarios with continuous collateral value appreciation.

In the high volatility scenario (Case Study 4), all proposed models demonstrated their ability to effectively manage collateral, similar to those in Case Studies 1 and 2.

Across all case studies, the multi-token adjustment models (Models 2 and 4) consistently outperformed the single-token adjustment models (Models 1 and 3) in terms of risk reduction and operational efficiency. The incorporation of a margin call threshold in Models 3 and 4 further contributed to the reduction of price fluctuation risk and operational costs compared to Models 1 and 2.

The multi-token adjustment model with a margin call threshold (Model 4) represents the optimal configuration for the proposed blockchain-based collateral management platform. This model offers the most advantageous trade-off between minimizing net credit risk and reducing the operational burden associated with frequent token transfers. By incorporating a margin call threshold, Model 4 effectively balances risk mitigation and system efficiency, making it the most suitable choice for practical implementation.

Table 3. Summary of the price fluctuation risk.

	Difference between actual and required collateral value (Percentage of model 0: %)									
	Maximum					**Average**				
Model	**0**	**1**	**2**	**3**	**4**	**0**	**1**	**2**	**3**	**4**
Case 1	100	0.00021	0.00043	54	52	100	0.00050	0.00093	73	62
Case 2	100	0.000066	0.00011	13	13	100	0.00012	0.00021	5.9	7.3
Case 3	100	100	0.00031	100	21	100	51	0.00072	78	33
Case 4	100	0.00013	0.00017	23	22	100	0.00023	0.00036	25	24

Table 4. Summary of operational costs.

	Number of margin call					**Number of additional token issuances**				
Model	**0**	**1**	**2**	**3**	**4**	**0**	**1**	**2**	**3**	**4**
Case 1	60	60	60	11	11	60	0	0	0	0
Case 2	60	60	60	31	29	60	0	0	0	0
Case 3	60	60	60	24	20	60	27	0	13	0
Case 4	60	60	60	21	20	60	0	0	0	0

3.2. Implications for Collateral Management

The simulation results demonstrate the potential of the proposed blockchain-based collateral management platform to enhance efficiency, reduce risks, and streamline operations in securities lending transactions. The automated and real-time collateral adjustments enabled by the platform can help financial institutions better manage their exposure to price fluctuation risk and counterparty risk.

The adoption of such a platform could have far-reaching implications for the financial industry, including improved risk management, increased operational efficiency, enhanced transparency and auditability, and the potential for new business models and innovative products and services.

3.3. Challenges and Future Research Directions

Despite the significant benefits of the proposed platform, several challenges need to be addressed for its successful implementation and adoption in the real world. These challenges include legal and regulatory issues, integration with existing systems, and interoperability with other blockchain networks.

Collaboration with regulators, legal experts, and industry partners is essential to develop a clear legal framework and establish industry-wide standards that enable the seamless integration of the platform into the financial ecosystem.

Future research directions include improving the scalability and performance of the platform, exploring its expansion to other financial instruments, developing cross-chain interoperability mechanisms, integrating privacy-preserving techniques, and developing automated compliance and reporting mechanisms.

4. Conclusion

4.1. Summary of Findings

This research presents a blockchain-based collateral management platform that leverages smart contracts and tokenization to automate and streamline the collateral management process in securities lending transactions. The simulation results demonstrate the platform's potential to reduce price fluctuation risk, improve operational efficiency, and enhance transparency and auditability.

The proposed platform offers significant advantages over traditional collateral management practices, including real-time collateral valuations, automated margin calls, and efficient collateral adjustments. The multi-token adjustment approach, in particular, provides greater flexibility and resilience under various market conditions.

4.2. Transdisciplinary Engineering Aspects: Dilemma Between Technological Innovation and Societal Implementation

The development of the blockchain-based collateral management platform showcases the potential of transdisciplinary approaches in addressing complex problems and driving innovation in the financial industry. This research offers to establish a more open and equitable financial market by enabling market participants to execute transactions using a single server, similar to the basic concept of P2P, regardless of their capital resources.

However, the integration of blockchain technology into existing financial systems presents significant challenges, particularly from a social and legal perspective. The financial industry is built upon a foundation of established practices, legal frameworks, and regulatory requirements that have evolved over many years. Adapting these deeply entrenched systems to accommodate blockchain technology would require a substantial overhaul of legal contracts, business processes, and regulatory frameworks.

This transformation process is likely to favor well-resourced participants, such as large financial institutions, who have the capital and expertise to navigate the complex legal and regulatory landscape. Smaller market participants, despite having access to the technological benefits of blockchain, may struggle to keep pace with the necessary changes in legal and operational frameworks. As a result, the implementation of blockchain technology in collateral management may inadvertently reinforce existing power imbalances, rather than promoting a more equitable financial system.

To fully realize the potential of blockchain technology in collateral management, it is essential to engage in a transdisciplinary dialogue that brings together experts from finance, engineering, law, and social sciences. This collaborative approach can help identify and address the complex challenges associated with the societal implementation of technological innovations.

4.3. Concluding Remarks

The proposed blockchain-based collateral management platform represents a significant step forward in addressing the challenges and inefficiencies associated with traditional collateral management practices in securities lending transactions. While there are challenges to be addressed, the potential benefits of the platform in terms of improved risk management, increased efficiency, and enhanced transparency make it a promising solution for the financial industry.

Continued research and development efforts, along with collaboration among stakeholders, will be essential to realize the full potential of blockchain technology in collateral management and drive the transformation of the financial landscape. As the technology matures and gains wider acceptance, it has the potential to revolutionize the way financial institutions manage collateral and conduct securities lending transactions, contributing to a more efficient, transparent, and resilient financial system.

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