

Examining the Effect of Smart Contract Features on Factors Affecting the Reduction of Non-Performing Bank Loans

Peyman Raziei¹, Seyyed Shamseddin Hosseini ^{2,*} and Seyyed Yahya Abtahi ³



Citation: Raziei, P., Hosseini, S. S., & Abtahi, S. Y. (2027). Examining the Effect of Smart Contract Features on Factors Affecting the Reduction of Non-Performing Bank Loans. *Business, Marketing, and Finance Open*, 4(6), 1-18.

Received: 14 April 2026
Revised: 02 September 2026
Accepted: 10 September 2026
Initial Publication: 28 September 2026
Final Publication: 01 June 2027



Copyright: © 2027 by the authors. Published under the terms and conditions of Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0) License.

- ¹ Researcher, Department of Economics, SR.C., Islamic Azad University, Tehran, Iran; 
² Associate Professor, Department of Business Economics, Faculty of Economics, Allameh Tabataba'i University, Tehran, Iran; 
³ Associate Professor, Financial Management Department, Faculty of Management, Ya.C., Islamic Azad University, Yazd, Iran; 

* Correspondence: Sh.hosseini@atu.ac.ir

Abstract: Non-performing bank loans are among the fundamental challenges facing Iran's banking system. Blockchain-based smart contracts, owing to their distinctive characteristics, have considerable potential for managing such loans. The present study aimed to examine the effect of smart contract features on factors affecting the reduction of non-performing bank loans. In terms of purpose, this research is applied, and in terms of methodology, it is descriptive-correlational. The statistical population consisted of 26 banks active on the Tehran Stock Exchange during the 2012–2025 period. A fixed-effects panel data regression model was employed to test the hypotheses using EViews software. Ten key smart contract features—including self-execution, use of blockchain, transparency, elimination of intermediaries, cost reduction, security, speed, real-time monitoring, interoperability, and automatic collateral registration—were considered as independent variables, while the score of factors affecting the reduction of non-performing bank loans was considered the dependent variable. The results of testing the second hypothesis indicated that all ten smart contract features had positive and statistically significant effects on the reduction of non-performing bank loans at the 95% confidence level. The F-statistic was 25.431 (Prob. = 0.000), and the adjusted coefficient of determination was 0.255, indicating an adequate model fit. The Durbin–Watson statistic (1.831) also confirmed the absence of autocorrelation. Smart contract features, particularly self-execution, transparency, security, and automatic registration, can directly and significantly contribute to reducing non-performing bank loans. These findings indicate that developing the technical and legal infrastructure required to implement smart contracts in Iran's banking system could provide an effective approach to credit risk management and substantially reduce non-performing bank loans.

Keywords: smart contracts, non-performing bank loans, blockchain, smart contract features, panel data.

1. Introduction

The banking industry has undergone a profound transformation as a result of the rapid development of digital technologies, the expansion of fintech ecosystems, and the increasing integration of decentralized infrastructures into conventional financial services. Among these developments, blockchain technology has attracted particular attention because of its capacity to restructure transaction processing, recordkeeping, verification, and contractual relationships in financial institutions. Unlike conventional centralized databases, blockchain relies on distributed ledgers in which transaction records can be validated, synchronized, and preserved across multiple nodes, thereby improving traceability, data integrity, and resistance to unauthorized

alteration. Within this technological architecture, smart contracts represent one of the most important functional innovations because they make it possible to translate contractual conditions into programmable rules that can be executed automatically when predefined conditions are satisfied. From a banking perspective, this characteristic transforms contracts from passive legal documents into active transactional mechanisms capable of initiating payments, validating compliance, recording contractual events, and enforcing selected obligations without continuous manual intervention [1-3].

Smart contracts are generally understood as digitally encoded agreements deployed on blockchain or comparable distributed-ledger infrastructures, through which contractual clauses can be executed automatically and deterministically. Their significance is not confined to technological automation; rather, they can alter the institutional architecture through which financial transactions are monitored, validated, and enforced. In traditional banking processes, lending agreements usually depend on several interconnected organizational functions, including credit departments, legal units, intermediaries, collateral registries, accounting systems, payment processors, and supervisory mechanisms. Fragmentation across these functions may generate information asymmetry, delays, administrative expenses, documentation inconsistencies, and opportunities for error or manipulation. Smart contracts can potentially reduce these frictions by integrating contractual logic with verifiable digital records and automated execution. Consequently, their possible applications extend from routine payment settlements to loan disbursement, collateral management, compliance monitoring, customer identification, audit trails, and credit risk management [4-6].

The growing interest in smart contracts is closely associated with broader efforts to modernize banking infrastructures through blockchain technology. Contemporary banking systems face increasing pressure to provide faster, safer, more transparent, and less costly financial services while simultaneously complying with stricter requirements concerning risk management, cybersecurity, data governance, auditing, and customer protection. Blockchain-based infrastructures have been proposed as mechanisms for improving the reliability of transactional records, facilitating near-real-time verification, reducing reconciliation costs, and enhancing institutional transparency. Empirical and conceptual studies increasingly suggest that blockchain implementation may improve operational efficiency and financial performance when it is integrated with appropriate organizational capabilities and governance structures [7-9]. Accordingly, the relevance of smart contracts to banking should be examined not merely as a technological innovation but as part of a broader transformation in the governance of financial transactions and risks.

One of the most persistent risk-management challenges in banking is the accumulation of non-performing loans and overdue receivables. Non-performing loans arise when borrowers fail to repay the principal or interest on their credit obligations within the agreed period, and their accumulation can adversely affect liquidity, profitability, capital adequacy, lending capacity, and overall financial stability. High levels of overdue banking claims may compel banks to increase provisions for doubtful accounts, allocate additional resources to debt collection, restrict new credit, and assume greater balance-sheet risk. At the systemic level, persistent non-performing loans may weaken the efficiency of financial intermediation and reduce the capacity of banks to support productive investment. For this reason, preventing loan delinquency and strengthening the mechanisms through which obligations are monitored and enforced are fundamental components of banking risk management. Blockchain-based innovations have increasingly been discussed in relation to credit risk because their traceability, data integrity, and automation capabilities may improve the monitoring and administration of lending relationships [6, 10].

The relationship between smart contracts and non-performing loans can be understood through several technological and organizational mechanisms. First, the self-executing nature of smart contracts may enable contractual actions to occur automatically once predefined criteria are fulfilled. For example, repayment schedules, notifications, penalties, collateral-related procedures, or transfers can be activated in accordance with encoded conditions. Automation may reduce delays associated with manual processing and increase consistency in the execution of financial agreements. In lending operations, delayed administrative responses and weak follow-up mechanisms may contribute to the deterioration of credit exposures. By contrast, automated contractual execution can allow banks to respond more quickly to changes in borrower status and reduce the operational dependency on manual intervention. The value-creation potential of smart contracts in banking has therefore been linked to their ability to streamline contractual processes, reduce repetitive administrative functions, and improve the efficiency of service delivery [4, 11].

Second, blockchain-based recordkeeping can strengthen the reliability and traceability of information used in credit management. Lending decisions and post-disbursement monitoring depend substantially on accurate and timely information regarding borrower behavior, payment history, collateral status, contractual amendments, and transaction flows. When these data are stored across disconnected databases or manually updated, inconsistencies may arise and impair the effectiveness of risk assessment. Blockchain can provide a tamper-resistant chronological record of transactions, thereby facilitating verification and reducing opportunities for unauthorized changes. Such traceability is particularly relevant to financial reporting, auditing, and risk supervision because it allows authorized stakeholders to reconstruct the history of transactions and contractual events with greater precision [12, 13]. In this respect, the integration of blockchain and smart contracts may contribute to more reliable monitoring of loan performance and facilitate earlier identification of problematic credit exposures.

Transparency constitutes another important characteristic of smart-contract-based systems. Information asymmetry has long been recognized as an important source of inefficiency in lending relationships, particularly when lenders have incomplete or delayed information about borrower behavior or the status of underlying assets. Blockchain-based infrastructures can create shared and verifiable records that improve visibility for authorized parties while preserving predefined access controls. Smart contracts can further enhance this transparency by making contractual rules explicit within executable code and by producing digital records of actions performed under those rules. In banking and financial reporting, greater transparency may improve accountability, reduce discrepancies among institutional records, and enhance the quality of verification and audit processes [12, 14]. For management of overdue claims, transparent contractual histories may make it easier to determine whether payment obligations have been fulfilled, identify deviations from agreed conditions, and initiate timely remedial measures.

The potential elimination or reduction of intermediaries is also central to the economic rationale for smart contracts. Conventional banking transactions often require multiple financial, legal, administrative, and technological intermediaries to authenticate documents, verify conditions, execute transactions, and resolve information inconsistencies. Although intermediaries may perform essential governance functions, excessive reliance on them can increase transaction costs and processing times. Blockchain systems permit distributed verification, while smart contracts allow predefined procedures to be performed automatically. This can reduce the need for certain forms of repetitive intermediation and thereby decrease administrative costs. Studies of blockchain-based banking models have emphasized the potential of fintech architectures to create value by simplifying transactional structures, reducing procedural inefficiencies, and redesigning service-delivery mechanisms [15, 16].

Such reductions in operational complexity may also support more efficient management of overdue claims, particularly when the collection and enforcement process requires coordination among several organizational units.

Cost reduction is therefore another dimension through which smart contracts may influence banking performance and loan management. Credit administration involves costs related to human resources, documentation, compliance, monitoring, information processing, legal services, auditing, and debt collection. When contractual procedures are automated and transaction records are shared through secure digital infrastructures, some of these costs may be reduced. Research on blockchain and bank performance has increasingly considered operational efficiency as an important mechanism linking technological adoption to organizational outcomes [7, 9]. Similarly, evidence concerning blockchain and dynamic capabilities suggests that technological value depends on the ability of banks to integrate digital tools into organizational processes and use them to reconfigure resources and improve responsiveness [8]. In the context of non-performing loans, reducing the costs of monitoring and executing loan contracts may enable banks to supervise larger portfolios more effectively and intervene at earlier stages of delinquency.

Security is another critical feature of blockchain-enabled smart contracts. Banking systems are exposed to multiple forms of cyber risk, including unauthorized access, data manipulation, identity fraud, fraudulent transactions, and interference with financial records. As digital banking expands, security threats increasingly affect both operational continuity and financial risk. Blockchain infrastructures are designed around cryptographic validation and distributed recordkeeping, which can increase resistance to certain forms of unauthorized alteration. However, blockchain does not eliminate cybersecurity risks, and smart contracts themselves may contain coding vulnerabilities or governance weaknesses. For this reason, effective deployment requires careful integration of technological security, organizational control, regulatory standards, and cybersecurity policies [2, 17]. Nevertheless, when properly designed, secure and tamper-resistant records may reduce fraud-related losses and improve the reliability of information used in credit monitoring.

Privacy and access management are equally important because banking data are highly sensitive. The usefulness of blockchain for transparency and traceability must therefore be balanced against the requirement to restrict unauthorized disclosure of customer information. Contemporary blockchain-based banking solutions increasingly focus on permissioned access, identity management, and Know Your Customer processes in order to combine verifiability with confidentiality. Blockchain-based access-control systems may enable financial institutions to determine which actors can view, validate, or modify particular data while maintaining an auditable record of access and transactions [18]. This capability has direct relevance to smart contracts because automated contractual operations often depend on access to borrower information, collateral data, credit histories, or repayment records. Effective privacy-preserving access management can therefore support the implementation of smart-contract-based loan monitoring without undermining the confidentiality obligations of banks.

Speed is another operational characteristic that distinguishes automated contractual systems from conventional procedures. Traditional loan administration may involve sequential approvals and manual verification, which can delay the identification of payment failures and the initiation of corrective measures. Smart contracts can potentially execute predetermined actions immediately after relevant data are received and verified. Faster transaction processing is particularly valuable when the timing of intervention affects the probability of recovering overdue claims. The broader literature on blockchain in banking has emphasized improvements in transaction processing, settlement, and information exchange as important areas of technological value [1, 6]. Accordingly, the speed of

smart contract execution may influence the ability of banks to manage repayment schedules, detect delinquency, and respond promptly to contractual breaches.

Closely related to speed is the capacity for real-time or near-real-time monitoring. Conventional credit monitoring frequently depends on periodic reporting, which may create a temporal gap between the deterioration of a borrower's position and the bank's awareness of that deterioration. Blockchain-enabled systems can record transactions continuously, while smart contracts can monitor specified conditions and automatically trigger alerts or predefined actions. Such functionalities may strengthen early-warning systems and improve the timeliness of credit risk responses. Research on blockchain-based credit risk management has highlighted the potential of distributed ledgers to improve the availability, reliability, and continuity of information relevant to borrower monitoring [10]. Likewise, the integration of blockchain with other digital technologies can improve information quality and facilitate more responsive financial reporting and auditing [14].

Interoperability with other banking systems also determines whether smart contracts can generate meaningful institutional benefits. Banks operate complex technological environments involving core banking platforms, payment systems, customer relationship management systems, enterprise resource planning systems, risk-management platforms, regulatory reporting infrastructures, APIs, and external information providers. Smart contracts that operate in isolation are unlikely to transform credit management substantially. Their value depends on their capacity to interact with relevant databases and information systems so that contractual actions reflect current and reliable information. Research on blockchain adoption in electronic banking indicates that technological compatibility, organizational preparedness, infrastructural conditions, and managerial factors substantially influence successful implementation [19]. Similarly, Iranian research on smart-contract models for banking emphasizes that implementation requires coordinated technological, institutional, and operational structures rather than the mere adoption of blockchain as an isolated technology [5].

Automatic registration and management of guarantees and collateral represent particularly important applications in relation to overdue bank claims. Collateral plays a major role in limiting credit losses, yet conventional collateral management may be affected by incomplete records, delays in updating ownership or valuation information, inconsistencies across registries, and administrative complications during enforcement. Smart contracts may be configured to record collateral-related conditions, update contractual records automatically, and trigger specified actions when repayment conditions are violated. Blockchain's immutable and traceable architecture can strengthen the reliability of records associated with guarantees and secured assets, although legal recognition and interoperability with official registries remain essential. In this respect, the future development of smart contracts in banking depends not only on their technical capacity but also on regulatory, legal, organizational, and institutional drivers that shape their enforceability and practical adoption [11].

The Iranian banking environment provides an especially relevant context for examining these issues. Iranian banks have increasingly engaged with electronic banking, fintech, digital payment systems, and emerging blockchain applications, while simultaneously facing longstanding challenges related to efficiency, risk management, financial transparency, and overdue receivables. Research conducted in Iran has identified multiple factors influencing blockchain adoption in electronic banking, including technical infrastructure, organizational capabilities, security considerations, institutional support, and management readiness [19]. Other studies have emphasized the impact of blockchain characteristics on banking innovation and the potential of blockchain-based fintech models to enhance value creation in financial and banking businesses [15, 16]. These findings indicate that blockchain is increasingly relevant to the strategic modernization of Iranian banking; however, the specific

relationship between smart contract characteristics and the management of non-performing loans remains insufficiently examined.

The auditing and reporting implications of blockchain are also important in the Iranian banking sector because effective management of overdue claims depends on credible accounting information, accurate classification of receivables, and reliable recognition of credit deterioration. Empirical research has suggested that blockchain can contribute to the quality of audit processes by enhancing information integrity, traceability, and verification [13]. These capabilities may become particularly valuable when banks need to evaluate provisions for doubtful accounts, document changes in repayment status, verify contractual modifications, or substantiate the enforcement of collateral. In this sense, the contribution of blockchain to non-performing loan management may extend beyond contract execution itself to the wider information environment within which credit risk is measured and controlled.

Despite these potential advantages, smart-contract adoption also involves significant constraints. Technical standardization, scalability, integration costs, legal enforceability, data privacy, cybersecurity, governance, and the accuracy of coded contractual rules remain substantial challenges. A smart contract can execute encoded instructions consistently, but it cannot independently determine whether those instructions reflect an equitable, legally enforceable, or economically appropriate contract. Furthermore, errors in coding or inaccurate external data may produce undesirable automated outcomes. The smart-contract literature therefore emphasizes that implementation should be accompanied by appropriate legal frameworks, governance mechanisms, dispute-resolution procedures, and technological safeguards [2, 6]. The development of smart contracts in the banking industry must consequently be viewed as a socio-technical transformation requiring alignment among technology, regulation, institutional structures, and banking management.

Furthermore, blockchain does not automatically improve bank performance merely because it is technologically advanced. Its organizational effects depend on implementation quality, managerial capabilities, process redesign, and strategic integration. Empirical findings concerning financial performance indicate that blockchain adoption can generate organizational benefits when it improves efficiency, data quality, transactional reliability, and service processes [9]. Likewise, research on dynamic capabilities suggests that banks must possess the ability to integrate, reconfigure, and exploit technological resources in order to translate blockchain investment into performance improvements [8]. This consideration is directly relevant to non-performing loan management, since the mere availability of smart contracts is unlikely to reduce overdue claims unless their features are embedded effectively in lending, monitoring, reporting, collateral management, and collection procedures.

The convergence of blockchain, artificial intelligence, and advanced digital reporting also points to a broader transformation in financial governance. Integrated digital frameworks can improve transparency, automate verification, strengthen anomaly detection, and provide decision makers with more timely information [14]. Similarly, developments in cybersecurity demonstrate that emerging banking technologies increasingly require integrated technological and policy responses rather than fragmented security solutions [17]. Smart contracts can therefore be conceptualized as one component of an evolving digital banking architecture in which transactions, contractual obligations, audit trails, identity systems, and risk indicators become increasingly interconnected.

Overall, prior research provides substantial evidence regarding blockchain adoption, smart-contract functionality, operational efficiency, auditing, financial innovation, cybersecurity, privacy, and credit risk management; however, there remains a notable empirical gap concerning how specific smart contract characteristics are associated with factors that can reduce non-performing loans at the bank level. Existing studies frequently address blockchain as a broad technological construct or focus on adoption intentions, performance

outcomes, financial reporting, or general credit-risk innovation, without simultaneously examining distinct smart contract characteristics such as self-execution, blockchain-based recording, transparency, intermediary reduction, cost reduction, security, execution speed, real-time monitoring, interoperability, and automatic collateral registration. Addressing this gap is important because these characteristics may operate through different mechanisms and may not contribute equally to the management of overdue claims. A feature-specific empirical assessment can therefore provide more actionable evidence for banking managers, policymakers, regulators, and technology developers regarding the aspects of smart contracts that are most relevant to credit-risk mitigation and loan recovery.

Accordingly, the aim of the present study is to examine the effect of smart contract use and specific smart contract characteristics on the factors affecting the reduction of non-performing bank loans among banks operating in Iran.

2. Methodology

In this study, the hypotheses were examined using econometric methods and linear regression analysis. This part of the research was descriptive-correlational and based on quantitative data. The statistical population consisted of statistical data from 26 active banks over the 2012–2025 period.

The models used in the present study were derived from the quantitative and qualitative analyses conducted in the preceding stages. The models corresponding to each hypothesis can be specified as follows:

Hypothesis 1: The use of smart contracts leads to a reduction in non-performing bank loans.

$$NLP_it = \beta_0 + \beta_1 LEN_it + \beta_4 SIZE_it + \beta_5 LEV_it + \beta_6 TANG_it + \beta_7 PROF_it + \varepsilon_0$$

Hypothesis 2: There is a significant relationship between smart contract features and the factors affecting the reduction of non-performing bank loans.

$$FNPL_it = \beta_0 + \beta_1 SCE_it + \beta_2 BCR_it + \beta_3 CTR_it + \beta_3 MID_it + \beta_3 CRC_it + \beta_3 SEC_it + \beta_3 SPE_it + \beta_3 RMT_it + \beta_3 INT_it + \beta_3 ASC_it + \beta_4 SIZE_it + \beta_5 LEV_it + \beta_6 TANG_it + \beta_7 PROF_it + \varepsilon_0$$

Dependent Variables

Factors Affecting the Reduction of Non-Performing Bank Loans (FNPL): This variable represents a score obtained in the previous stage from the mean scores of the factors affecting the reduction of non-performing bank loans.

Non-Performing Loan Index (NPL): This refers to the ratio of non-performing bank loans to total loans and credit facilities for which repayment of principal or interest has been delayed beyond a specified period, usually 90 days or three months.

Independent Variables

Smart Contract Use Index (LEN): This variable is assigned a value of 1 when smart contracts are used and a value of 0 when smart contracts are not used.

Self-Execution of Contracts (SCE): This refers to the reduction in personnel costs associated with the processing and execution of credit facilities.

Use of Blockchain for Information Recording (BCR): This refers to information technology and software costs.

Transparency in Contract Terms and Execution (CTR): This refers to the storage and reporting of information relating to credit facilities and risk.

Elimination of Financial and Legal Intermediaries (MID): This refers to consulting service costs and intermediary fees.

Reduction in Contract Execution Costs (CRC): This refers to operational costs and the costs associated with processing credit facilities.

High Security Against Manipulation and Fraud (SEC): This refers to losses resulting from fraud and provisions for doubtful receivables.

Speed of Obligation Performance (SPE): This refers to the time required for debt collection or fund circulation.

Real-Time Monitoring of Contract Status (RMT): This is calculated as the number of contracts that can be monitored in real time divided by the total number of contracts.

Interoperability with Other Systems (INT): This refers to investments in enterprise resource planning (ERP) systems, application programming interfaces (APIs), and banking software.

Automatic Registration of Guarantees and Collateral (ASC): This refers to provisions for non-performing loans and collateral management.

Control Variables

Firm Size (SIZE): This control variable is calculated as the logarithm of the bank's total assets at the end of the reporting period.

Financial Leverage (LEV): The ratio of total liabilities to total assets.

TANG: The ratio of tangible fixed assets to total assets.

Profitability (PROF): The ratio of operating profit to total assets.

To collect data related to the research hypotheses, the study examined banks listed on the stock exchange. After extracting the required information through Rahavard Novin software and the databases of the Securities and Exchange Organization, the data were consolidated into Excel columns and used to calculate the research variables. The research hypotheses were subsequently tested using EViews software.

3. Findings and Results

In this section, the collected data were classified and analyzed using appropriate statistical techniques consistent with the type of variables and their measurement scales. First, descriptive statistics were used to summarize the collected information through distribution tables and graphical representations. Inferential statistics were then employed to test and analyze the research hypotheses.

In general, the methods used to process and summarize collected information are referred to as descriptive statistics. Descriptive statistics are concerned with describing a population or sample, and their purpose is to calculate the parameters of the research population or sample. The skewness and kurtosis of the data were examined. Skewness is a measure of the symmetry or asymmetry of a distribution function. For a completely symmetrical distribution, skewness is zero; for an asymmetric distribution with a longer tail toward higher values, skewness is positive; and for an asymmetric distribution with a longer tail toward lower values, skewness is negative. Kurtosis indicates the degree of peakedness of a distribution. In other words, kurtosis measures the height of the distribution curve at its maximum point, and the kurtosis value for a normal distribution is 3.

Table 1. Skewness and Kurtosis of the Research Variables

Variable	Mean	Maximum	Minimum	Standard Deviation	Skewness	Kurtosis
NLP	0.143	0.599	-0.999	0.471	0.037	0.061
LEV	2.093	3.995	0.067	1.132	0.482	0.249
SIZE	18.342	30.995	11.014	6.277	0.172	-0.017
FNPL	0.288	3.921	0.001	0.568	-0.295	0.337
SCE	0.677	0.799	0.550	0.071	0.315	0.901

TANG	0.258	0.385	0.161	0.049	0.293	0.194
PROF	0.118	0.760	0.001	0.091	0.359	0.102
BCR	0.067	0.145	0.016	0.065	0.412	0.521
CTR	0.631	1.031	0.001	0.302	0.381	-0.250
LEN	0.809	0	1	0.246	0.155	-0.051
MID	0.719	0.991	0.011	0.488	0.453	0.089
CRC	0.402	0.641	0.104	0.112	0.189	0.524
SEC	0.672	0.801	0.098	0.307	0.576	0.334
SPE	0.698	0.852	0.113	0.211	0.512	0.244
RMT	0.601	0.731	0.152	0.251	0.199	0.054
INT	0.727	0.841	0.121	0.236	0.601	0.234
ASC	0.519	0.798	0.110	0.247	0.534	0.099

Positive kurtosis indicates that the peak of the distribution is higher than that of the normal distribution, whereas negative kurtosis indicates that the peak is lower than that of the normal distribution. For example, in the t-distribution, where the dispersion of data is greater than in the normal distribution, the height of the curve is lower than that of the normal curve. Table 1 presents the results of the examination of data skewness.

As shown in Table 1, the observed skewness values for all variables fall within the range of -2 to +2. Therefore, in terms of skewness, all variables can be considered normally distributed and their distributions are approximately symmetrical. The kurtosis values of the variables also fall within the range of -2 to +2, indicating acceptable normality in terms of kurtosis. Following the examination of skewness and kurtosis, normality was assessed using the Kolmogorov–Smirnov test. When assessing data normality, the null hypothesis that the data follow a normal distribution is tested at a 5% significance level. Therefore, if the significance level obtained from the test is greater than or equal to 0.05, there is insufficient evidence to reject the null hypothesis that the data are normally distributed. In other words, the distribution of the data is considered normal. The statistical hypotheses for the normality test were formulated as follows:

H0: The data corresponding to each variable are normally distributed.

H1: The data corresponding to each variable are not normally distributed.

All variables were found to be normally distributed.

Table 2. Results of the Kolmogorov–Smirnov Test for All Variables

Variable	Significance Level	Error Level	Accepted Hypothesis	Conclusion
NLP	0.066	0.05	H0	Normal
LEV	0.388	0.05	H0	Normal
SIZE	0.091	0.05	H0	Normal
FNPL	0.432	0.05	H0	Normal
SCE	0.088	0.05	H0	Normal
TANG	0.901	0.05	H0	Normal
PROF	0.125	0.05	H0	Normal
BCR	0.123	0.05	H0	Normal
CTR	0.122	0.05	H0	Normal
LEN	0.157	0.05	H0	Normal
MID	0.149	0.05	H0	Normal
CRC	0.122	0.05	H0	Normal
SEC	0.195	0.05	H0	Normal
SPE	0.152	0.05	H0	Normal
RMT	0.177	0.05	H0	Normal
INT	0.146	0.05	H0	Normal
ASC	0.201	0.05	H0	Normal

The Kolmogorov–Smirnov test was conducted using SPSS 21. Because the significance levels were greater than the specified error level, all data were considered normally distributed. This section presents the results obtained from estimating the models and testing the research hypotheses. For each hypothesis, detailed outputs generated by the statistical software are presented in separate tables to facilitate comparison and evaluation of the hypotheses.

Hypothesis 1: The use of smart contracts leads to a reduction in non-performing bank loans.

$$NLP_it = \beta_0 + \beta_1 LEN_it + \beta_4 SIZE_it + \beta_5 LEV_it + \beta_6 TANG_it + \beta_7 PROF_it + \varepsilon_0$$

The null hypothesis (H0) and alternative hypothesis (H1) for testing the first hypothesis model were formulated as follows:

H0: $\beta_1 = 0$; there is no significant relationship between the two variables.

H1: $\beta_1 \neq 0$; there is a significant relationship between the two variables.

The results of testing the first hypothesis model based on the estimation of the above model are presented in Table 3.

Table 3. Statistical Results of the First Hypothesis Model

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.547	0.290	-2.022	0.009
LEN	0.027	0.007	4.321	0.004
PROF	-0.002	0.001	-2.416	0.016
TANG	0.109	0.076	3.358	0.008
LEV	0.0165	0.002	0.315	0.687
SIZE	-0.016	0.024	-0.639	0.523
Effects Specification				
Effect			S.D.	Rho
Cross-section random			0.156	0.017
Period fixed (dummy variables)			—	—
Idiosyncratic random			1.172	0.983
Weighted Statistics				
Statistic	Value	Statistic	Value	
R-squared	0.270	Mean dependent variable	10.034	
Adjusted R-squared	0.260	S.D. dependent variable	1.364	
S.E. of regression	1.172	Sum squared residuals	676.294	
F-statistic	26.044	Durbin–Watson statistic	1.857	
Prob(F-statistic)	0.000			
Unweighted Statistics				
Statistic	Value	Statistic	Value	
R-squared	0.269	Mean dependent variable	10.034	
Sum squared residuals	688.272	Durbin–Watson statistic	1.824	

Considering the F-statistic of 26.043 and comparing it with the corresponding critical F-value, it can be concluded that the fitted regression model is statistically significant overall at the 1% significance level. The adjusted coefficient of determination indicates that the independent variables included in the model explain approximately 26% of the variation in the non-performing loan index. Furthermore, examination of the Durbin–Watson statistic of approximately 1.856 confirms the absence of autocorrelation among the regression model's disturbance terms, as the statistic is close to 2.

As shown in Table 3, the estimated coefficient and t-statistic for the use of smart contracts are positive and statistically significant at the 5% significance level. Therefore, H0 is rejected, and the first research hypothesis is supported at the 5% significance level. Based on this evidence, it can be concluded that the use of smart contracts leads to a reduction in non-performing bank loans.

Hypothesis 2: There is a significant relationship between smart contract features and the factors affecting the reduction of non-performing bank loans.

$$\text{FNPL_it} = \beta_0 + \beta_1\text{SCE_it} + \beta_2\text{BCR_it} + \beta_3\text{CTR_it} + \beta_3\text{MID_it} + \beta_3\text{CRC_it} + \beta_3\text{SEC_it} + \beta_3\text{SPE_it} + \beta_3\text{RMT_it} + \beta_3\text{INT_it} + \beta_3\text{ASC_it} + \beta_4\text{SIZE_it} + \beta_5\text{LEV_it} + \beta_6\text{TANG_it} + \beta_7\text{PROF_it} + \varepsilon_0$$

The null hypothesis (H0) and alternative hypothesis (H1) for testing the second hypothesis model were formulated as follows:

H0: $\beta_1 = 0$; there is no significant relationship between the two variables.

H1: $\beta_1 \neq 0$; there is a significant relationship between the two variables.

The results of testing the second hypothesis model based on the estimation of the above model are presented in Table 4.

Table 4. Statistical Results of the Second Hypothesis Model

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.418	0.325	-2.026	0.009
SCE	0.034	0.013	2.549	0.011
BCR	0.124	0.001	3.280	0.008
CTR	0.156	0.034	4.524	0.000
MID	0.144	0.024	4.404	0.000
CRC	0.150	0.064	4.780	0.000
PROF	-0.002	0.001	-2.416	0.016
TANG	0.109	0.076	3.358	0.008
LEV	0.0165	0.002	0.315	0.687
SIZE	-0.016	0.024	-0.639	0.523
RMT	0.116	0.044	4.114	0.000
INT	0.134	0.026	4.552	0.000
ASC	0.141	0.049	4.189	0.000
SEC	0.0124	0.001	2.145	0.009
SPE	0.015	0.002	3.142	0.008
Effects Specification				
Effect			S.D.	Rho
Cross-section random			0.133	0.013
Period fixed (dummy variables)			—	—
Idiosyncratic random			1.178	0.988
Weighted Statistics				
Statistic		Value	Statistic	
R-squared		0.267	Mean dependent variable	
Adjusted R-squared		0.255	S.D. dependent variable	
S.E. of regression		1.178	Sum squared residuals	
F-statistic		25.431	Durbin–Watson statistic	
Prob(F-statistic)		0.000		
Unweighted Statistics				
Statistic		Value	Statistic	
R-squared		0.265	Mean dependent variable	
Sum squared residuals		692.061	Durbin–Watson statistic	

Considering the F-statistic of 25.431 and comparing it with the corresponding critical F-value, it can be concluded that the fitted regression model is statistically significant overall at the 1% significance level. The adjusted coefficient of determination indicates that the independent variables included in the model explain approximately 25.5% of the variation in the factors affecting the reduction of non-performing bank loans. Furthermore, examination of the Durbin–Watson statistic of 1.831 confirms the absence of autocorrelation among the disturbance terms of the regression model because the statistic is close to 2.

As shown in Table 4, the estimated coefficients and t-statistics associated with self-execution of contracts, use of blockchain for information recording, transparency in contract terms and execution, elimination of financial and legal intermediaries, reduction in contract execution costs, high security against manipulation and fraud, speed of obligation performance, real-time monitoring of contract status, interoperability with other systems, and automatic registration of guarantees and collateral are positive and statistically significant at the 5% significance level. Therefore, H_0 is rejected, and the second research hypothesis is supported at the 5% significance level. Based on this evidence, it can be concluded that there is a statistically significant relationship between smart contract features and the factors affecting the reduction of non-performing bank loans.

4. Discussion and Conclusion

The present study examined the effect of smart contract use and specific smart contract characteristics on factors contributing to the reduction of non-performing bank loans. The findings of the first hypothesis showed that the use of smart contracts had a positive and statistically significant effect on the reduction of non-performing bank loans. The estimated coefficient for smart contract use was positive and significant at the 5% level, while the overall regression model was significant, with an F-statistic of 26.044 and an adjusted R-squared of 0.260. In other words, the variables included in the model explained approximately 26% of the variation in the non-performing loan index. The Durbin–Watson statistic was also close to 2, indicating no problematic autocorrelation in the regression residuals. These findings support the proposition that the application of smart contracts can contribute to more effective management of overdue banking claims by increasing automation, reducing procedural delays, strengthening transaction traceability, and facilitating the execution of contractual obligations.

This result is consistent with previous studies emphasizing the transformative potential of blockchain and smart contracts in banking operations. Smart contracts can automate contractual processes and reduce dependence on manual intervention, thereby increasing the speed and consistency of financial transactions. Earlier research has highlighted that smart contracts create value for banks by reducing administrative complexity and improving the execution of financial agreements [4]. Likewise, blockchain-based banking models have been introduced as mechanisms capable of improving transaction processing, record integrity, and the automation of contractual obligations [1]. From this perspective, the significant relationship observed in the present study can be explained by the fact that overdue claims often arise or deteriorate in environments characterized by delayed monitoring, fragmented documentation, and inefficient enforcement. By embedding predefined contractual conditions within an automated digital infrastructure, smart contracts can reduce these operational weaknesses and support more timely responses to repayment delays.

The findings also align with studies indicating that blockchain-based systems can enhance banking performance by improving operational efficiency and strengthening organizational capabilities. Krampe and Margaritella emphasized the relationship between blockchain implementation and operational efficiency in banking, suggesting

that distributed ledger technologies can simplify processes, reduce reconciliation requirements, and improve transaction management [7]. Similarly, empirical evidence has shown that blockchain can positively contribute to bank performance when it is integrated into organizational processes and supported by appropriate technological capabilities [9]. Ogunrinde et al. also showed that the value of blockchain depends partly on banks' dynamic capabilities and their ability to integrate digital technologies into operational and strategic processes [8]. Therefore, the significant effect of smart contract use found in this study can be interpreted as reflecting the operational advantages arising from automation, better data availability, and more efficient coordination across banking processes.

The second hypothesis investigated the relationship between ten specific smart contract characteristics and the factors affecting the reduction of non-performing bank loans. The results indicated that all ten characteristics—self-execution, blockchain-based information recording, transparency in contract terms and execution, elimination of financial and legal intermediaries, reduction in contract execution costs, security against manipulation and fraud, speed of obligation performance, real-time monitoring of contract status, interoperability with other systems, and automatic registration of guarantees and collateral—had positive and statistically significant effects. The overall model was statistically significant, with an F-statistic of 25.431, and the adjusted R-squared value of 0.255 indicated that approximately 25.5% of the variation in the factors affecting the reduction of non-performing bank loans was explained by the model. The Durbin–Watson statistic of 1.831 also suggested the absence of serious autocorrelation. Taken together, these findings demonstrate that the relationship between smart contracts and overdue loan reduction is multidimensional and cannot be attributed to a single technological feature.

The positive effect of self-execution can be explained by the ability of smart contracts to perform predefined contractual actions automatically when predetermined conditions are met. This reduces dependence on manual administrative procedures and minimizes delays in the implementation of lending-related obligations. The finding is consistent with studies describing automation as one of the central sources of value created by smart contracts in financial institutions [2, 11]. In the context of loan management, self-executing clauses can support automatic reminders, repayment processing, penalty activation, or initiation of collateral-related procedures. Such mechanisms can shorten the time between a contractual event and the bank's response, thereby reducing the likelihood that delayed obligations will develop into more serious non-performing exposures.

The significant effect of blockchain-based information recording is also theoretically and empirically plausible. Blockchain provides a distributed and difficult-to-alter record of transactions, which can enhance the reliability and traceability of financial information. Previous studies have emphasized the importance of blockchain in improving transparency, auditability, and information integrity within banking and financial reporting systems [12, 13]. When repayment records, collateral information, contractual changes, and credit events are securely recorded, banks can monitor borrowers more effectively and identify deviations from agreed obligations at an earlier stage. The present finding is therefore consistent with the argument that more reliable and traceable information can strengthen credit monitoring and reduce operational uncertainty in the management of non-performing loans.

Transparency in contract terms and execution was also positively and significantly related to factors reducing non-performing bank loans. This result is particularly important because information asymmetry is one of the principal challenges in credit relationships. When contractual terms are unclear or monitoring information is fragmented, both banks and borrowers may face uncertainty regarding obligations, penalties, payment schedules, and enforcement procedures. Smart contracts can make predefined conditions more explicit and create auditable records of the actions performed under those conditions. Research on blockchain-enabled financial reporting has

similarly emphasized the role of transparent and verifiable data in increasing accountability and reducing discrepancies [14]. The results of the present study suggest that transparency may improve both preventive and corrective aspects of credit risk management by clarifying contractual responsibilities and providing more accurate evidence when repayment problems arise.

The positive impact of reducing financial and legal intermediaries is also compatible with the existing literature. Smart contracts can decrease the need for certain forms of repetitive intermediation by allowing transactions and contractual conditions to be validated through digital protocols. Previous studies have suggested that fintech and blockchain-based financial models can generate value by reducing unnecessary intermediaries and simplifying transactional structures [15, 16]. In relation to overdue claims, excessive administrative layers may delay decision-making, increase the cost of collection, and create inconsistencies in communication among borrowers, banks, legal departments, and third parties. Reducing such friction can improve the efficiency of follow-up procedures and enable banks to react more promptly when contractual obligations are not fulfilled.

The significant effect of reduced contract execution costs further supports the operational-efficiency interpretation of smart contract adoption. Loan administration is resource intensive and requires ongoing expenditures for documentation, processing, verification, monitoring, legal review, and collection. Automation can reduce some of these expenses by standardizing repetitive tasks and lowering the need for manual intervention. This result is consistent with research linking blockchain adoption to improvements in operational efficiency and organizational performance [7, 9]. Reducing the cost of monitoring individual contracts can be especially important for banks with large credit portfolios because it may allow more extensive supervision without proportionate increases in human and administrative resources. Consequently, banks may be able to identify problematic loans earlier and allocate collection resources more efficiently.

Security against manipulation and fraud was another smart contract feature with a positive and significant effect. This finding is supported by literature emphasizing cryptographic security, tamper resistance, and distributed validation as important properties of blockchain-based systems. Cybersecurity has become increasingly important in modern banking as financial institutions face threats involving identity theft, record manipulation, unauthorized transactions, and data breaches [17]. Blockchain-based access management and Know Your Customer solutions have also been proposed to improve data protection and strengthen the reliability of banking processes [18]. In the context of credit management, secure transaction histories and protected contractual records can reduce opportunities for fraudulent modifications, unauthorized collateral changes, or manipulation of payment information, thereby supporting more accurate and enforceable loan management.

The positive relationship between speed of obligation performance and reduced non-performing loans can be interpreted through the importance of timeliness in credit monitoring and collection. Smart contracts can execute coded actions rapidly once required conditions have been met, reducing delays inherent in manual approval and processing procedures. Prior research has identified faster transaction processing as one of the principal benefits of blockchain-based financial systems [1, 6]. In loan management, delayed reactions to missed payments may allow credit problems to worsen. Faster execution can enable banks to initiate reminders, restrictions, repayment adjustments, or collection measures before borrowers' obligations become substantially overdue. Therefore, the present finding indicates that execution speed is not merely a convenience but may have direct implications for credit risk control.

Real-time monitoring of contract status was likewise found to have a positive and significant effect. This is consistent with the growing emphasis on continuous data availability and early-warning mechanisms in digital

banking. Blockchain-based systems can provide near-real-time records of transactions and contractual events, while smart contracts can continuously evaluate whether predefined conditions have been satisfied. Previous research on blockchain-based credit risk management has suggested that distributed ledger technologies can improve the timeliness and reliability of information available for monitoring borrowers and credit exposures [10]. The ability to detect early deviations from repayment schedules can be critical because the probability of successful intervention generally declines as delinquency persists. Thus, real-time monitoring can support proactive rather than reactive management of non-performing loans.

Interoperability with other systems was also significantly associated with the reduction of non-performing bank loans. This finding indicates that smart contracts create greater value when they are integrated with existing banking platforms rather than implemented as isolated technological solutions. Banking operations rely on interconnected systems for customer data, payments, accounting, credit scoring, collateral management, risk reporting, and regulatory compliance. Research conducted in the Iranian banking context has emphasized that technological compatibility, organizational readiness, and integration capabilities are important determinants of successful blockchain adoption [5, 19]. Accordingly, a smart contract that can exchange information with enterprise resource planning systems, APIs, core banking platforms, and risk-management databases can provide more complete and current information for credit monitoring and can execute more accurate responses to changes in borrower status.

The significant effect of automatic registration of guarantees and collateral is particularly relevant to the management of non-performing loans because collateral recovery represents one of the primary mechanisms available to banks when borrowers default. In conventional systems, collateral management may be undermined by outdated records, fragmented registries, documentation delays, or uncertainty regarding ownership and valuation. Smart contracts can help automate the recording and updating of collateral-related conditions and create verifiable transaction histories. This finding is compatible with broader research on the future of smart contracts in banking, which identifies institutional integration, legal recognition, and automated asset-related processes as important drivers of their development [11]. Reliable and automated collateral records can strengthen a bank's capacity to respond to default and reduce administrative uncertainty during enforcement.

Taken together, the findings of the study strongly support the view that blockchain and smart contracts may contribute to credit risk management not through a single isolated mechanism but through a combination of automation, transparency, security, cost reduction, traceability, interoperability, and real-time monitoring. This interpretation is consistent with systematic assessments of blockchain in banking, which show that its effects extend across operational efficiency, risk management, transaction processing, financial reporting, cybersecurity, and institutional governance [6]. It is also consistent with studies in the Iranian context showing that blockchain characteristics can facilitate financial innovation and improve the quality of banking processes when adequate infrastructure and organizational support are available [15, 16]. Therefore, the results suggest that smart contract implementation may provide a technologically integrated approach to reducing non-performing loans, provided that the banking system possesses the necessary regulatory, technical, and managerial capacity.

At the same time, the findings should not be interpreted as implying that smart contracts alone can eliminate the structural causes of non-performing loans. Credit delinquency can originate from macroeconomic instability, borrower insolvency, weak underwriting, inadequate collateral valuation, governance problems, economic shocks, and sector-specific risks. Smart contracts primarily improve the mechanisms through which contractual obligations are recorded, monitored, and executed. Their effectiveness therefore depends on the quality of underlying lending

decisions and the broader institutional environment. This interpretation is consistent with research emphasizing that blockchain-based performance improvements depend on organizational capabilities, regulatory structures, and integration with existing banking processes [8, 11]. Accordingly, smart contracts should be viewed as a complementary instrument for credit risk management rather than as a substitute for sound lending policies, effective risk assessment, and prudent banking governance.

The present study is subject to several limitations. First, the analysis was restricted to 26 banks and to the 2012–2025 period, which may limit the generalizability of the findings to other financial institutions, non-bank credit organizations, or banking systems operating under different regulatory and technological conditions. Second, several smart contract characteristics were operationalized through financial, operational, or technological proxies, and these measures may not fully capture the multidimensional nature of actual smart contract deployment. Third, the study relied on secondary banking data and quantitative modeling and therefore could not directly assess managerial perceptions, technological readiness, legal enforceability, customer acceptance, or implementation challenges. Fourth, although the regression models included several control variables, other macroeconomic and institutional factors such as inflation, interest rates, economic growth, regulatory changes, credit policies, and borrower-level characteristics may also influence non-performing loans. Finally, the observational nature of the data limits the ability to establish definitive causal relationships.

Future studies should extend the present research by examining larger and more diverse samples that include public and private banks, credit institutions, fintech firms, and banks from different countries. Longitudinal studies could investigate whether the effects of smart contract adoption strengthen or weaken over different stages of implementation. Future researchers may also incorporate macroeconomic indicators, borrower-level risk variables, regulatory characteristics, and bank governance factors into more comprehensive models. Structural equation modeling, dynamic panel models, difference-in-differences designs, or quasi-experimental methods could be used to provide stronger evidence regarding causal mechanisms. Qualitative studies involving banking managers, credit officers, regulators, legal experts, and technology specialists could also clarify the institutional and operational barriers to implementation. Furthermore, future research should examine possible mediating and moderating mechanisms, such as digital readiness, organizational agility, cybersecurity capability, regulatory support, and technological interoperability.

Bank managers and policymakers should consider developing phased smart contract implementation programs that prioritize credit monitoring, repayment automation, collateral registration, and early-warning mechanisms. Banks should integrate smart contracts with core banking systems, credit risk platforms, customer databases, enterprise resource planning systems, and secure APIs to ensure reliable and timely information exchange. Particular attention should be given to cybersecurity, access control, data privacy, code auditing, and contingency procedures before large-scale deployment. Regulatory authorities should establish clear legal standards concerning the enforceability of digitally executed contractual clauses, electronic collateral records, dispute resolution, and accountability for coding errors. Banks should also train employees in blockchain-based operations and redesign internal procedures so that technological automation complements rather than conflicts with existing risk-management responsibilities. Pilot projects should be evaluated using measurable indicators such as delinquency rates, recovery time, administrative costs, fraud losses, processing time, and collateral-enforcement efficiency before smart contracts are implemented across the entire banking portfolio.

Authors' Contributions

Authors equally contributed to this article.

Ethical Considerations

All procedures performed in this study were under the ethical standards.

Acknowledgments

Authors thank all participants who participate in this study.

Conflict of Interest

The authors report no conflict of interest.

Funding/Financial Support

According to the authors, this article has no financial support.

References

- [1] G. W. Peters and E. Panayi, "Understanding Modern Banking Ledgers Through Blockchain Technologies: Future of Transaction Processing and Smart Contracts on the Internet of Money," pp. 239-278, 2016, doi: 10.1007/978-3-319-42448-4_13.
- [2] K. C. Lee and T. K. Chen, "Smart Contracts: Opportunities and Challenges," *Journal of Internet Banking and Commerce*, vol. 25, no. 1, pp. 1-14, 2020.
- [3] F. Schär, "Decentralized finance: On blockchain- and smart contract-based financial markets," *Federal Reserve Bank of St. Louis Review*, vol. 103, no. 2, pp. 153-174, 2021.
- [4] Z. Ebrahimi Ghaffar, "Smart Contracts and Their Role in Value Creation from the Perspective of Banks," presented at the Seventh Annual Conference on Electronic Banking and Payment Systems, 2017.
- [5] N. Eynollahi, F. Ahmadi, R. Mohammadipour, and M. Arayesh, "Presenting a blockchain technology model in smart contracts for the banking industry," *Investment Knowledge*, vol. 14, no. 53, pp. 179-200, 2023.
- [6] Y. Said, A. M. Khaddar, L. Hassine, A. Eddaoui, and T. Chafiq, "The impact of blockchain on the banking sector: A systematic review of applications, challenges, and future directions," *Asia and the Global Economy*, vol. 6, no. 1, 2026, doi: 10.1016/j.aglobe.2025.100133.
- [7] T. Krampe and F. Margaritella, "Blockchain and operational efficiency in the banking industry," *Journal of Financial Technology*, vol. 11, no. 1, pp. 33-59, 2024. [Online]. Available: https://www.jnabm.ir/article_734179.html.
- [8] A. Ogunrinde, C. De-Pablos-Heredero, J. L. Montes-Botella, and L. Fernández-Sanz, "The impact of blockchain technology and dynamic capabilities on banks' performance," *Big Data and Cognitive Computing*, vol. 9, no. 6, p. 144, 2025, doi: 10.3390/bdcc9060144.
- [9] R. Almadadha, "Blockchain and Financial Performance: Empirical Evidence from Major Australian Banks," (in English), *Frontiers in Blockchain*, vol. 8, p. 1463633, 2025, doi: 10.3389/fbloc.2025.1463633.
- [10] M. Mutamimah, A. Suryani, and A. Made Dwi, "Credit Risk Management Innovation in Bank Based on Blockchain Technology," in *International Congress on Information and Communication Technology*, Singapore, 2024: Springer Nature Singapore, doi: 10.1007/978-981-97-3556-3_3.
- [11] O. A. Adeli and M. H. Maleki, "A Framework for Identifying and Analyzing Drivers affecting the Future of Smart Contracts in the Banking Industry," *Islamic Economics and Banking*, vol. 14, no. 50, pp. 261-287, 2026.
- [12] Z. Wang, H. Li, and T. Zhou, "Integration of blockchain and cloud computing in banking audit: Information traceability and report quality," *Information Systems Frontiers*, vol. 26, no. 2, pp. 215-235, 2024. [Online]. Available: <https://www.mdpi.com/1911-8074/17/8/372>.
- [13] M. Moslemi, M. Mehrara, and A. Moslemi, "The effect of blockchain technology on the quality of the audit process: An empirical study in the banking sector using panel data," *Islamic Economics and Banking*, vol. 13, no. 49, pp. 439-461, 2024.
- [14] S. R. Hashemi Jouybari, S. M. Hosseini, and H. Abedi, "An Integrated Framework of Artificial Intelligence and Blockchain for Enhancing Transparency and Efficiency in Financial Reporting and Auditing of Islamic Banks in the Digital Economy Context," 2025.

- [15] A. Sadeghi, A. Irajpour, and R. Ehtesham Rathi, "Presenting a fintech-based blockchain technology value model in financial and banking businesses," *Program and Development Research*, vol. 5, no. 1, pp. 183-223, 2024.
- [16] M. Mohammadi, "The Impact of Blockchain Characteristics on Banking Financial Innovations in Iran," *Quarterly Journal of New Applied Studies in Management, Economics and Accounting*, vol. 6, no. 3, pp. 73-84, 2024. [Online]. Available: https://www.nasme-journal.ir/article_176385.html.
- [17] T. N. Tran, "Systematic Review of Cybersecurity in Banking: Evolution from Pre-Industry 4.0 to Post-Industry 4.0 in Artificial Intelligence, Blockchain, Policies and Practice," arXiv, 2025.
- [18] A. V. Kulkarni, T. Mondal, and D. Modi, "Enhancing Privacy in Banking Systems: A Blockchain-Based Access Management and KYC Solution," *Cogent Business & Management*, 2025, doi: 10.1080/23311975.2025.2570063.
- [19] A. Zarei, M. Modarresi, and M. Ebrahimi, "Factors affecting the use of blockchain technology in electronic banking service management: A case study of Bank Mellat," *Industrial Technology Development Quarterly*, vol. 22, no. 57, pp. 35-50, 2024.