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Modeling the Dynamics of Banking Risk Interactions Using Cognitive Maps

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ABSTRACT

The main purpose of the article is to model the dynamics of cause-and-effect relationships of banking risks using the method of constructing fuzzy cognitive maps. To construct a fuzzy cognitive map, a system of indicators of banking risks in Ukraine was formed, their dynamics in 2020–2025 were analyzed, and a correlation matrix of relationships was constructed. This allowed us to characterize the main cause-and-effect relationships between banking risks and formulate recommendations for risk management. Based on the analysis of banking risks, a moderate level of credit risks, a low level of liquidity risk, an increase in banks' operational risks, a decrease in the level of interest rate risks, and an increase in currency market risks due to an increase in banks' currency liabilities in 2020–2025 were identified. The study found that there is an inverse negative relationship between credit, interest rate, operational and liquidity risks of banks in Ukraine due to a significant share of non-performing loans and a moderate level of concentration of counterparty loans. In addition, a direct relationship was found between market risk and liquidity risk, interest rate, and operational risks. This indicates the importance of increasing assets in foreign currency and reducing the volume of open currency positions of banks. Interest rate risk (reduction in net banking profitability) negatively affects lending, including in foreign currency, as well as liquidity risk. At the same time, interest rate risk, measured as net interest margin and net interest spread, has a direct relationship with operational risk (i.e., with an increase in these indicators, the volume of operational risk will increase). This means the need to supervise interest rates on new loans and deposits.

KEYWORDS

banking risks, cognitive maps, lending, credit risk, operational risk, liquidity, interest rate risk, inflation.

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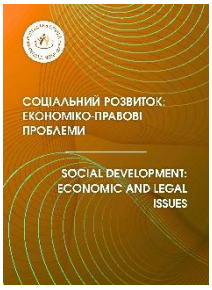

Моделювання динаміки причинно-наслідкових зв'язків банківських ризиків на основі когнітивних карт

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СТАТТЯ

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АНОТАЦІЯ

Основною метою статті є моделювання динаміки причинно-наслідкових зв'язків банківських ризиків із використанням методики побудови нечітких когнітивних карт. Для побудови нечіткої когнітивної карти було сформовано систему індикаторів банківських ризиків в Україні, проаналізовано їх динаміку у 2020–2025 роках та побудовано кореляційну матрицю зв'язків. Це дозволило охарактеризувати основні причинно-наслідкові зв'язки між банківськими ризиками та сформувати рекомендації для управління ризиками. На підставі аналізу банківських ризиків виявлено помірний рівень кредитних ризиків, низький рівень ризику ліквідності, збільшення операційних ризиків банків, зниження рівня процентних ризиків, зростання валютних ринкових ризиків через збільшення валютних зобов'язань банків у 2020–2025 роках. В процесі дослідження встановлено, що між кредитними, процентними, операційними ризиками та ризиком ліквідності банків в Україні існує обернений негативний зв'язок через значну частку непрацюючих кредитів та помірний рівень концентрації кредитів контрагентів. Крім цього, виявлено прямий зв'язок між ринковим ризиком та ризиком ліквідності, процентним, операційними ризиками. Це вказує на важливість нарощування активів в іноземній валюті та скорочення обсягу відкритої валютної позиції банків. Процентний ризик (скорочення чистої банківської дохідності) негативно позначається на кредитуванні, в тому числі в іноземній валюті, а також на ризику ліквідності. При цьому, процентний ризик, виміряний як чиста процентна маржа та чистий процентний спред, має прямий зв'язок із операційним ризиком (тобто при збільшенні цих індикаторів зростатиме обсяг операційного ризику). Це означає потребу в нагляді за процентними ставками за новими кредитами та депозитами.

КЛЮЧОВІ СЛОВА

банківські ризики, когнітивні карти, кредитування, кредитний ризик, операційний ризик, ліквідність, процентний ризик.

1. Introduction

Cognitive maps as one of the methods for mathematical assessment of the causal relationships of banking risks have not been widely used. At the same time, there is a significant potential for the practical application of cognitive maps for risk management in the banking system. This is due to the increasing complexity of the economic and political environment of bank operations, nonlinear relationships between banking risks, increased banking supervision and the need for risk management [15].

Traditional risk assessment methods (expert methods, heat maps, financial stress indices) do not sufficiently fully cover the complex causal relationships between risks and their impact on banking activities. Thus, innovative methods for assessing the relationships between different types of risks in banking activities based on quantitative indicators are needed.

The use of cognitive maps allows us to move to adaptive and predictive risk management, which is more effective in decision-making [15].

2. Literature Review

The study of banking risks using cognitive models is devoted to the works of V. V. Zubova [14; 15], O. M. Kolodizev, S. M. Kyrkach, E. M. Ogorodnaya.

Cognitive mapping is considered as a tool for establishing cause-and-effect relationships of banking risks. Cognitive maps are built on the basis of indicators of banking risks, expert assessments and mathematical models. Cognitive maps reflect cause-and-effect relationships between banking risk factors and allow for their analysis in a more comprehensive way [4].

Fuzzy cognitive maps are used by decision-makers in the process of risk management and the formation of corrective/preventive measures to minimize risks [3]. Among the features of the cognitive mapping method is the ability to model complex systems and relationships in systems with limited or missing data [2]. Cognitive maps reflect possible changes in the system through cause-and-effect relationships and the initial state of the system. This method allows you to reduce dependence on expert opinions compared to other decision-making methods.

Cognitive modeling is one of the most widely used methods for measuring and identifying banking risks, which allows you to increase the accuracy of predicting the occurrence of adverse events and form management decisions to minimize their negative impact [13]. The use of cognitive models has become relevant due to the growth of currency, credit, investment and other types of risks in banking.

Table 1. The main advantages of cognitive maps for modeling the dynamics of cause-and-effect relationships of banking risks

Advantages of cognitive maps by criteria	
Nonlinearity	Taking into account the nonlinearity of financial relationships and processes
Complexity	Taking into account the complex relationships between micro- and macro-factors of influence on banking activities (macroeconomic, market factors)
Efficiency	The ability to make more effective management decisions to minimize risks
Accuracy	Accuracy of forecasting risk dynamics
Uncertainty	Taking into account the uncertainty of the external environment

Source: Formed by the authors based on [2; 13; 14].

It should be noted that the NBU uses several tools to monitor systemic risks that threaten financial stability: the Financial Cycle Index, the Financial Stress Index, the financial sector risk map, in which banks play a key role, for a comprehensive assessment and analysis of changes, identification of the occurrence of risks in the short term, justification of the choice of macroprudential policy instruments [9]. The risk map assesses macroeconomic, currency risks, credit risk of non-financial corporations, households, capital, profitability and liquidity risks on a scale from 0 to 10 (0 - low risks, 10 - high risks) based on the arithmetic average of the indicators used to measure each group of risks. At the same time, heat maps do not allow to assess the cause-and-effect relationships between banking risks and the impact of macroeconomic variables on banking risks.

3. Problem Statement

The main objective of the study was to model the dynamics of causal relationships of banking risks using the method of constructing fuzzy cognitive maps. To achieve the goal, the following tasks were set: development of a methodology for assessing banking risks based on cognitive maps; assessment of the dynamics of banking risks in Ukraine in 2020-2026; construction of a fuzzy cognitive map of causal relationships of banking risks.

4. Methods and Materials

This article uses the fuzzy cognitive map construction method to identify cause-and-effect relationships between banking risks. At the first stage of the study, a system of indicators was formed for the quantitative assessment of banking risks (credit, liquidity risk, interest rate, market, operational) in Ukraine in 2020-2026 (January - April 2026). The selection of banking risk indicators was carried out taking into account the current prudential standards, which are determined by the National Bank of Ukraine to assess the financial stability of the banking system. At the second stage of the study, an analysis of banking risk indicators in Ukraine in 2020-2026 was conducted. For this, statistical data from the National Bank of Ukraine and the International Monetary Fund were collected. At the third stage, the correlation analysis method was applied to identify cause-and-effect relationships between banking risks. Based on the correlations between banking risks, a fuzzy cognitive map was constructed and recommendations for banking risk management were formulated.

5. Results and Discussion

In the context of European integration into the common financial space of the EU, risk-based supervision of the banking system is becoming relevant in Ukraine. In this regard, there is a need to apply new methods for measuring banking risks and the causal relationships between them. Fuzzy cognitive maps (FCM) are one of the methods of cognitive modeling and analysis of relationships between various factors influencing economic processes and phenomena.

According to the "Regulations on the Organization of the Risk Management System in Ukrainian Banks and Banking Groups", approved by the Resolution of the National Bank of Ukraine dated 11.06.2018 No. 64, the following risks of banks and banking groups are distinguished [11]: credit risk; liquidity risk; interest rate risk; market risk; operational risk; compliance risk (probability of losses, sanctions, lack of income or losses) and other significant risks (risks in the economic, political, social spheres of the country that lead to banking losses or lack of income; reputation risks; settlement risks; strategic risks and others).

The methodology for assessing banking risks based on cognitive maps is based on the calculation of the main risk indicators that exist in the banking system (Table 2). To determine the cause-and-effect relationships between banking risks, a correlation matrix was calculated, which reflects the direction (direct, reverse) and the strength of the relationship between risks in the interval [-1;1]. The correlation matrix served as the basis for the development and construction of a cognitive map of cause-and-effect relationships between banking risks.

Table 1. Calculation of banking risks

Risk	Indicator for calculation	Formula
Credit risk	Share of non-performing loans (NPL), %	Volume of non-performing loans, UAH million / Volume of loans, UAH million × 100%
Liquidity risk	Prudential LCR (liquidity coverage ratio) or ratio of high-quality liquid assets (HQLA) to net expected cash outflows within 30 days	Liquid assets (liquid assets) / net expected cash outflow ×100%
Interest rate risk	Net interest margin (NIM, %) or net interest spread (%)	Net interest margin is the ratio of net interest income to bank assets, % Net interest spread is the difference between interest rates on new loans and interest rates on new deposits, %

Risk	Indicator for calculation	Formula
Market risk	Open currency position (mln. UAH) or share of currency assets (%)	An open currency position is the difference between currency assets and currency liabilities Share of currency assets as the ratio of currency assets to assets, %
Operational risk	Standardized approach according to Basel III with application of a marginal risk weighting factor (0.12 – 0.18)	15% × Average net interest income and average net commission income of banks for 3 years

Source: Formed by the authors based on [7; 10-12].

Credit risk is the probability of additional losses or lack of income due to non-fulfillment of obligations assumed by the counterparty/debtor in accordance with the contract [11].

During 2020-2024, the level of credit risks of banks was high due to the significant volume and share of non-performing loans of the corporate sector and individuals (Fig. 1). In 2025, the level of credit risks decreased to 30.29%, and in 2026, to 13.92%.

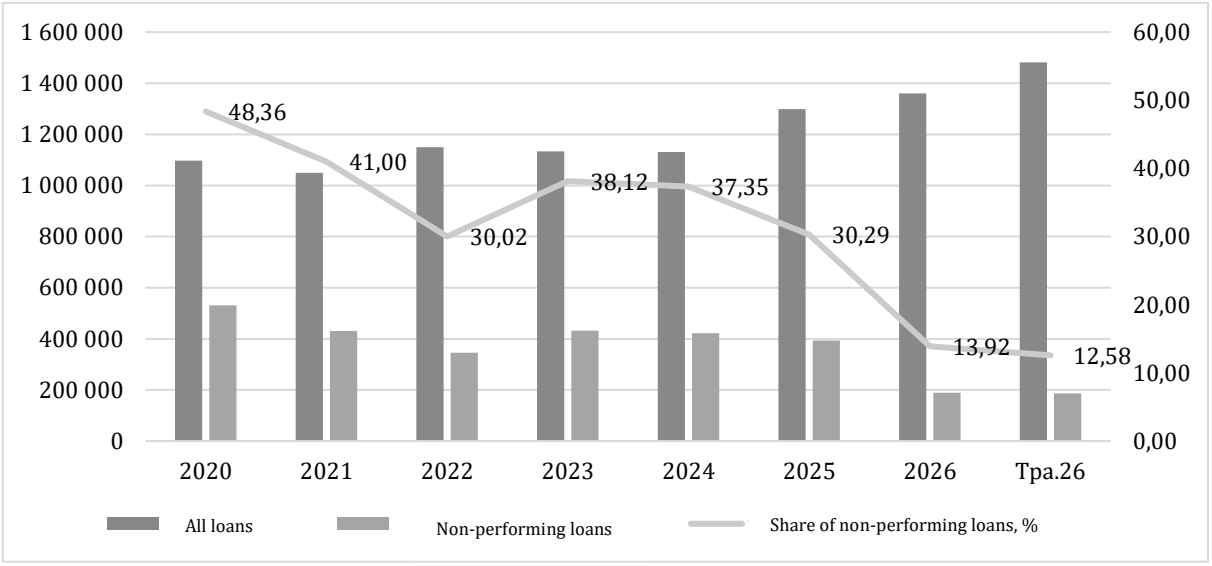

Figure 1. Credit risk assessment of banks in Ukraine in 2020-2026 (UAH million / %)

Source: Built by the authors based on [12].

The dynamics of prudential economic standards of banks in Ukraine indicate an average level of riskiness of banking operations with counterparties, with a reduction in 2023-2025, which does not exceed the maximum amount of credit risk per counterparty established by the NBU (25%). The norm of large credit risks of banks is within the limits of the norms established by the NBU, with a reduction in 2020–2025 (significantly below the 8-fold amount of regulatory capital) (Table 2). Despite the moderate growth in the concentration of large loans, the level of bank risks remains controlled due to the increase in the regulatory capital of banks to UAH 269.89 billion in 2023 and UAH 267.46 billion in 2024.

Operational risk is defined as the probability of additional losses or losses or loss of income due to errors or deficiencies in the organization of the bank's work or internal processes, unintentional or intentional actions of personnel, the impact of external factors or failures in the operation of bank systems [11].

Unlike market and credit risk, operational risk has various sources of origin, high frequency of occurrence and a high degree of impact on bank profits, which leads to a high level of complexity of its assessment and a lower level of ability to measure. Any person, system or process, even external events such as natural crises, can be a source of operational risk [1].

The Basel II Capital Accord of 2004 introduced three approaches to calculating regulatory capital for operational risk: the basic indicator approach, the standardized approach and the advanced measurement approach (AMA). AMA is the most complex, although it has the potential to reduce regulatory capital by up to 20–40% (Neil, Andersen, & Hager, 2009). Various methods have been proposed within the framework of AMA, such as time series, loss distribution approach, extreme value

theory and causal modeling methods. Causal models are usually the basis for risk management in two ways. First, they provide an assessment of the distribution of losses, as well as a deep understanding of the causal mechanism of the occurrence of risk events. This can help in assessing risk reduction measures and improving risk management decisions [1].

Table 2. Dynamics of prudential (economic) standards of banks in Ukraine in 2020–2026

Normative		2020	2021	2022	2023	2024	2025	2026	Absolute deviation (2025-2020)
		on 01.12						on 01.05	
H7	Maximum credit risk limit per counterparty (no more than 25%)	19.85	19.40	18.95	14.55	16.01	16.57	14.36	-3.3
H8	Large credit risk limit (no more than 8 times regulatory capital)	84.60	70.75	88.08	58.14	75.33	93.85	70.08	9.3
H9	Maximum credit risk limit for transactions with related parties (no more than 25%)	3.80	4.25	3.65	2.12	1.10	4.99	3.71	1.2

Source: Formed by the authors based on [6].

Ukraine has approved amendments to the "Regulations on the procedure for determining the minimum amount of operational risk by banks of Ukraine" dated 24.12.2019 No. 156 [12], which take into account the update of the approach to determining capital requirements by banks to cover the minimum amount of operational risk in the European Union from January 1, 2025. Since 2021, a standardized approach has been in effect in Ukraine, which was based on the position of the Basel Committee on Banking Supervision "Basel III: Final Agreement on Post-Crisis Reforms" of 2017 [10]. According to this approach, the calculated amount of operational risk to be covered by capital does not depend on the historical amount of losses from operational risk events of banks. Also, the Regulation of 24.12.2019 No. 156 [12] provides for the use of a differentiated approach to establishing the maximum operational risk weighting coefficient from 0.12 to 0.18, depending on the size of the business indicator component that assesses operational risk (the components of the business indicator are net interest income, net commission income of banks, and other operating income). At the same time, for almost all banking institutions, the weighting coefficient is 0.12. This means a decrease in the need for capital to cover operational risks.

Based on the results of calculations of net interest income, net commission income, and net other operating income, the value of operational risk was calculated for all banks in Ukraine in general using a weighting factor of 0.12. As a result, it was found that the operational risk of banks gradually increased in 2020-2025, amounting to UAH 38.638 billion in 2025 (Fig. 2).

Interest rate risk is interpreted as the probability of additional losses or a lack of income due to a significant impact of changes in bank interest rates, which affects the economic cost of capital and net interest income [11]. Direct interest rate risks affect the profitability of loans, deposit costs, and changes in the value of financial instruments in accordance with changes in interest rates. Indirect interest rate risks affect the borrower's solvency and lead to changes in credit risks.

In 2020–2025, interest income of banks in Ukraine increased from UAH 147.7 billion to UAH 410.8 billion, i.e. by UAH 263.0 billion or 178.0%. At the same time, interest expenses increased from UAH 62.9 billion to UAH 138.9 billion, which indicates an increase of UAH 76.0 billion or 120.8%. The outpacing growth rates of interest income compared to interest expenses ensured an increase in net interest income from UAH 84.8 billion to UAH 271.9 billion, or by UAH 187.1 billion (220.5%).

The growth of interest rates in 2022–2023 was due to the tightening of the NBU's monetary policy in conditions of martial law and high inflationary pressure. This led to an increase in the cost of borrowed resources and potentially increased the interest rate risk of banks due to a possible mismatch in the terms and conditions of revaluation of assets and liabilities.

At the same time, a significant increase in net interest income and the preservation of a positive interest rate spread indicate effective adaptation of banks to changes in interest rates. In 2024–2026, a gradual stabilization of interest rates is observed, which indicates a decrease in the level of interest rate risk and an increase in the predictability of banks' interest income.

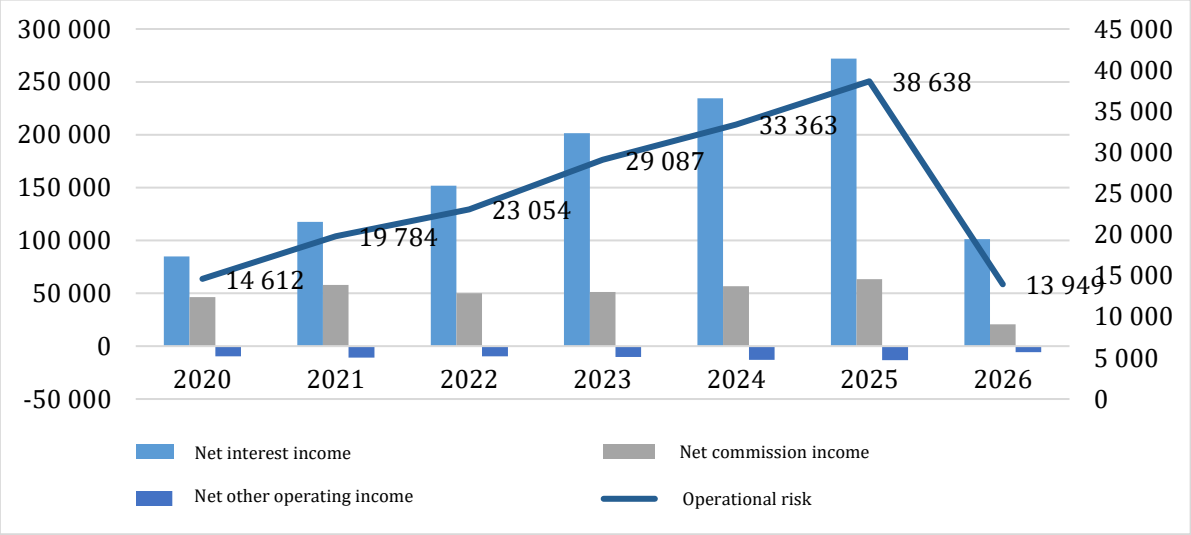

Figure 2. Dynamics of net interest and commission income, other operating income of banks and the calculated volume of operational risk of banks in Ukraine in 2020–2026, UAH million.

** January – April 2026*

Source: Built by the authors based on [5].

Table 3. Dynamics of net interest income of banks and interest rates in Ukraine in 2020–2026

Normative	2020	2021	2020	2023	2024	2025	2026*	Absolute deviation (2025–2020), mln. UAH
Interest income, UAH million	147,743	168,746	217,053	304,437	351,588	410,764	155,286	+263,021
Interest expense, UAH million	62,895	51,097	65,358	103,043	117,290	138,864	54,016	+75,969
Net interest income, UAH million	84,848	117,649	151,695	201,394	234,298	271,900	101,270	+187,052
Net interest margin, %	4.84	5.94	6.76	7.33	7.19	7.28	2.50	+2.45
Interest rate on new loans, %	10.28	8.91	14.05	17.20	14.94	14.57	14.71	+4.28
Interest rate on new deposits, %	5.15	4.13	7.31	10.57	7.42	8.75	8.83	+3.59
Interest spread, %	5.13	4.79	6.74	6.63	7.51	5.82	5.88	+0.69

** January – April 2026*

Source: Formed by the authors based on [5].

Liquidity risk is the probability of additional losses or shortfall in income due to the inability of banks to support financing the increase in assets and/or fulfill their obligations in due time [11].

The calculated values of liquidity coverage ratios for 16 systemically important banks of Ukraine (average value 336.9%) indicate the absence of liquidity risk and the high ability of banks to support the increase in assets as of May 1, 2025. According to the International Monetary Fund, the liquidity coverage ratio in Ukraine was above the regulatory value of 100%, amounting to 298.77% in 2022, 306.17% in 2023, 259.53% in 2024. Until 2022, in Ukraine, the short-term liquidity ratio H6 (not less than 60%) was calculated to measure liquidity risk, which was 88.55% in 2020 and 89.36% in 2021.

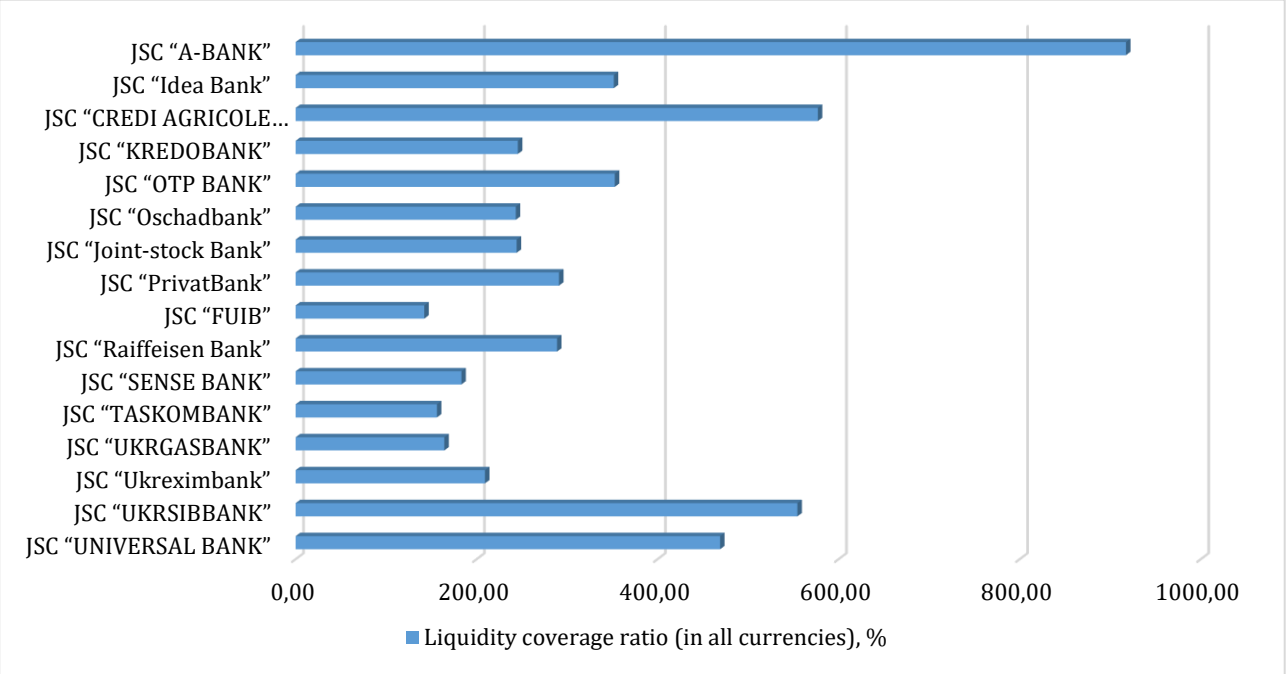

Figure 3. Liquidity coverage ratio of systemically important banks in Ukraine as of May 1, 2026, %

Source: Formed by the authors based on [11].

Market risk is the probability of additional losses or losses, lack of income due to the adverse impact of market variables on the price/value of bank instruments: interest rates, foreign exchange rates and other factors [3].

Table 4. Dynamics of banking risk indicators in Ukraine, 2020-2025

Risk indicator	2020	2021	2022	2023	2024	2025	Absolute deviation (2025–2020)
Share of non-performing loans (NPL), %	48.36	41	30.02	38.12	37.35	30.29	-18.07
Maximum credit risk ratio per counterparty	19.85	19.4	18.95	14.55	16.01	16.57	-3.28
LCR (liquidity coverage ratio)	-	-	298.77	306.17	259.53	336.9	-
H6 Short-term liquidity ratio	88.55	89.36	-	-	-	-	-
Net interest margin (NIM), %	4.84	5.94	6.76	7.33	7.19	7.28	+2.45
Net interest spread, %	5.13	4.79	6.74	6.63	7.51	5.82	+0.69
Open currency position, UAH million	-55,803	-37,399	-65,300	-28,147	-32,351	-55,167	+636
Share of currency assets in banks' assets, %	34.40	30.01	32.02	28.64	28.73	26.22	-8.18
Volume of operational risk, UAH million	14,612	19,784	23,054	29,087	33,362	38,638	+24026

Source: Formed by the authors

The correlation matrix of banking risks allows us to determine the average level of direct relationship between credit risk and open currency position, the share of currency assets in bank assets (currency market risk); the average level of negative inverse relationship between credit risk and liquidity, interest rate risk and operational risk; the average inverse relationship of liquidity risk with interest rate risk (net interest spread) and with currency market risk; the direct low relationship of liquidity risk with operational risk (Table 5).

Table 5. Correlation matrix of banking risk indicators

Indicator	NPL, %	H7, %	LCR, %	NIM, %	NIS, %	OpenFX	ForeignCA	OR
NPL, %	1.00							
H7, %	0.36	1.00						
LCR, %	-0.27	0.04	1.00					
NIM, %	-0.80	-0.83	0.03	1.00				
NIS, %	-0.49	-0.65	-0.54	0.72	1.00			
OpenFX	0.28	-0.62	-0.40	0.31	0.22	1.00		
ForeignCA	0.60	0.74	-0.27	-0.83	-0.30	-0.41	1.00	
OR	-0.69	-0.78	0.15	0.88	0.55	0.23	-0.92	1.00

Source: Formed by the authors

Correlation analysis indicates the complexity of the cause-and-effect relationships between the main indicators of banking risks (Table 6).

Table 6. Cause-and-effect relationships between banking risks

Risks	Risk indicators	Cause-and-effect relationships
Credit risk	Share of non-performing loans (NPL), % Ratio of maximum credit risk per counterparty	Direct average correlation with currency market risks Inverse average, high correlation with liquidity risk, interest rate and operational risks
Liquidity risk	Ratio of LCR (liquidity coverage ratio)	Direct average relationship with credit risk Inverse average relationship with interest rate risk (net interest spread) Inverse average relationship with currency market risk Direct low relationship with operational risk
Interest rate risk	Net interest margin (NIM, %) Net interest spread (NIS, %)	High inverse relationship with credit risk Inverse medium relationship of NIS with liquidity Direct medium relationship with foreign exchange market risks (OpenFX), but high inverse relationship with the share of foreign exchange assets in banks' assets High direct relationship with operational risks
Market risk	Open currency position (mln. UAH) Share of currency assets (%)	Average direct relationship with credit risk, interest rate, operational risks Inverse average relationship with liquidity
Operational risk	Volume of operational risk, mln. UAH	Inverse high correlation with credit risk, currency market risk Direct high correlation with interest rate risk, low correlation with currency market risk

Source: Formed by the authors

The constructed cognitive map allows us to clearly characterize the cause-and-effect relationships between the main banking risks: with an increase in credit risks, banks face a decrease in liquidity; with an increase in credit risks (for example, an increase in loan concentration), banks' interest rate risks decrease (the net interest margin or interest rate yield of banks on loans decreases); with an increase in credit risks, operational risk decreases (in fact, the net operating and commission yield of banks decreases). At the same time, with an increase in credit risks, the level of currency market risks increases, which may indicate an increase in the currency open position (Fig. 4).

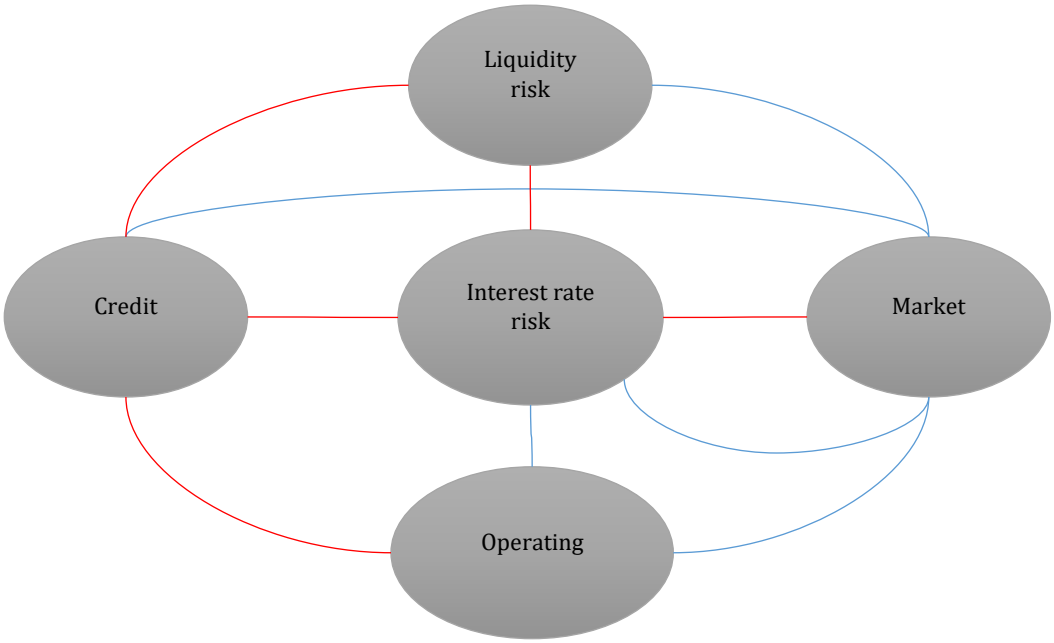

Figure 4. Cognitive map of cause-and-effect relationships between banking risks, %
Source: Formed by the authors.

An increase in interest rate risks (reduction in profitability or reduction in net interest spread) will lead to a reduction in currency market risks and, at the same time, to an increase in operational risks (in fact, the net profitability of banks will increase).

6. Conclusions

The constructed cognitive map of cause-and-effect relationships between banking risks based on the correlation matrix allows for the formulation of recommendations for risk management. The regulation of credit risks and non-performing loans should be a priority for the regulator, given their significant impact on bank liquidity and solvency, interest rate risk, and net profitability from bank lending and servicing. In particular, it is important to ensure a further reduction in the volume of non-performing loans and reduce the level of concentration of counterparty loans. It is important to ensure the growth of banks' assets in foreign currency, given their positive impact on lending, bank liquidity, net profitability, and operational stability. Interest rate risks negatively affect credit, currency market risks, and liquidity. Therefore, it is important to ensure an optimal balance between net interest rates on new loans and new deposits.

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