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The complex relationship between credit and liquidity risks: a linear and non-linear analysis for the banking sector

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This article explores the reciprocal link between credit risk and liquidity risk in Tunisia. To the best of our knowledge, no study has examined the linear and non-linear relationships between credit risk (CR) and liquidity risk (LR) taken in both directions. We utilized a sample of Tunisian banks from 2000 to 2018 to investigate this link in both causative directions and within a linear and non-linear framework. Unlike previous investigations, we used two empirical approaches. The linear link was assessed using the Seemingly Unrelated Regression (SUR) model, whilst the non-linear correlation was investigated using the Panel Smooth Transition Regression (PSTR) model.The results of the linear analysis show that credit and liquidity risks are positively related in both directions. The non-linear analysis proves that there is a threshold impact in both connections. More specifically, we discovered that the NPLs ratio, which measures credit risk, is 9.87%, while the LTD ratio measures liquidity risk, which is 102%. Below this threshold, there is a negative and significant relationship; beyond these thresholds, the effect is positive but only significant for the influence of credit risk on liquidity risk.

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Introduction

Banks are crucial to the financing of the economy, particularly in those areas that fall within the debt category. The theory of financial intermediation states that the raison d'êtreof banks is to provide liquidity and to transform risks (Pop et al. 2018; Magwedere and Marozva, 2022). On the one hand, liquidity was recognized as one of the most critical inputs of banking operations (Cornett et al. 2011; Habib et al. 2022) and credit was regarded one of the most profitable assets (Van Greuning and Bratanovic 2003). On the other hand, weak level of liquidity risk (LR) and bad quality of loans were considered the most critical risks that threaten bank profitability and bank stability (Chowdhury et al. 2023; Habib et al. 2022) After the global financial crisis of 2008, great importance has been granted to LR by both policymakers and academics (Hamdi and Hakimi, 2019). For credit risk (CR), Reinhart and Rogoff (2011) consider that NPLs are the primary determinant of bank failures and banking crises.

Banking literature is abundantly reported by investigations focused either on the determinants of CR and LR (Antony 2023; Naoaj 2023; Alnabulsi et al. 2022; Ferreira 2022; Ghenimi et al. 2021; Hakimi and Zaghdoudi 2017, Misman and Bhatti 2020) or the linkage between LR, CR and bank profitability or bank stability. (Hakimi and Zaghdoudi, 2017; Cofitalan, 2022; Setiawan et al. 2021; Faiz, 2022). However, less abundant studies explored the complex relationship between the two risks. For example, Boussaada et al. (2022) tested the threshold effect in the LR and nonperforming loans (NPLs) relationship for a sample of MENA banks in one direction running from LR → to NPLs. Similarly, Pop et al. (2018) [1] explored the same association for European banks. Imbierowicz and Rauch (2014) tested the linkage between these two major sources of US commercial banks. In the framework of COVID-19, Magwedere and Marozva (2022) investigated the connection between LR and the CR of banks having a base of operations in South Africa.

To date, no study has explored the causal linkage between NPLs and LR in the two causal directions. We assume that (i) the relationship between the two risks could be reciprocal, and (ii) there is an optimal level of LR that affects the NPLs ratio. This study fills this gap and analyses the linear and possible non-linear relationship between these LR and CR. Using data related to the most active Tunisian banks in financing the Tunisian economy throughout 2000–2018, this paper's goal is twofold. First, it aims to explore the complex linkage between NPLs and LR in a linear framework. Second, it investigates the possible reciprocal non-linear relationship between the risks in the Tunisian banking sector.

Given that the banking industry in Tunisia is recognized as being the most active in funding the country's economy and that it is very beneficial to investigate the relationship between the two main risks, Tunisia is deemed a good case study. For example, domestic credit provided by the banking sector[1] in % of GDP crossed from 53.39% in 2000 to 68.14% in 2018. The banking sector is still considered the primary source of investment finance. The Tunisian stock exchange market is less developed and contained only 82 listed firms in 2018, with 24,380 million TND as market capitalization. Furthermore, more than 50% of the listed firms are financial institutions. For this reason, we are interested in such relations in the Tunisian context.

This work distinguishes itself from previous research and adds to the corpus of knowledge in several fields.. Firstly, as far as we are aware, no study has looked at the association between NPLs and LR in both the linear and non-linear directions.. Contrary to Boussaada et al. (2022), which tested only the non-linear relationship between LR and NPLs in one causal direction running from LR → to NPLs, we explore in this study the two causal directions. Second, contrary to previous studies that investigate either linear or non-linear analysis, in the current, we address this issue following two empirical methodologies. The first one (SUR method) is devoted to assessing the linear relationship, and the second one (PSTR model) aims to explore the non-linear relationship. Third, this study defined two optimal thresholds for the two reciprocal risks. This makes it possible for the Tunisian banks and the Tunisian Central Bank to implement some regulatory reforms not to surpass these thresholds.

The remainder of this work is organized as follows. A overview of the literature is included in Section "Literature review". Data and empirical methods are presented in Section "Data and empirical method". Empirical results are covered in the fourth section. The conclusion and discussion of policy proposals are included in Section "Conclusion and policy recommendations".

Literature review

The two biggest and most dangerous risks to bank performance and stability, according to banking literature, are credit and LRs. (Hamdi and Hakimi 2019; Reinhart and Rogoff 2011; Boussaada et al. 2022; Magwedere and Marozva 2022; Faiz 2022). Strongly documented in the literature focused on the determinants of credit and LRs (Ghenimi et al. 2021; Hakimi and Zaghdoudi 2017). Few research, meanwhile, have looked at how credit and LR are reciprocally related. There are conflicting findings in the literature about the relationship between CR and liquidity, with the majority of findings favoring the positive correlation. Several empirical studies concluded that the two risks are positively correlated (Cai and Zhang 2017; He and Xiong 2012; Magwedere and Marozva 2022. However, few studies supported either the negative (Cai and Thakor 2008; Wagner 2007; Faiz 2022) or the non-significant effect (Imbierowicz and Rauch 2014). Besides reviewing studies based on the positive or negative effect, the literature on the credit-LR relationships is divided into linear and non-linear analyses.

Magwedere and Marozva (2022) have conducted research on the correlation between CR and liquidity in the context of the COVID-19 pandemic. Throughout the years 2018–2021, they used quarterly panel data from 13 banks with headquarters in South Africa. The empirical results indicate that LR and CR are positively related. According to the authors, CR declined and liquidity improved prior to COVID-19. Nevertheless, no discernible difference in effect was seen between the two indicators during COVID-19. Hakimi et al. (2022) used a sample of 38 MENA banks over the period 2004–2017 to assess the interactional relationship between CR, LR, and bank performance. Findings of the Seemingly Unrelated Regression indicate that credit and LR are positively and significantly correlated. The authors also found that the two risks decrease bank profitability. This unfavorable effect was found in both the single and interactive effects.

According to Cai and Zhang's (2017) analysis of a sample of Ukrainian banks from 2009 to 2015, there is a positive correlation between CR and LR. The authors suggest that banks that recorded a high level of NPL ratio seem unable to respond to withdrawal demands. The authors conclude that with international banks, the favorable correlation is stronger. A 1% rise in CR raises LR by 0.061 percent.

The reciprocal link between CR and LR, as well as their respective and combined effects on the stability of banks, were examined by Khan and Yilmaz (2022). From 2004 to 2016, a selection of commercial banks were employed in South Asian countries. Their results show that there is a positive reciprocal relationship between CR and LR.

In the framework of COVID-19, Magwedere and Marozva (2022) examined the link between LR and the CR of 13 banks in South Africa from 2018 to 2021. According to their findings, CR and LR had a positive relationship during the whole period. They then separated the data into two equal periods (COVID-19 and

pre-COVID-19). They determined that COVID-19 had a negative and substantial impact on liquidity, and that there was no correlation between CR and LR during the pandemic period.

Chen and Lin (2016) used a sample of banks belonging to 43 countries during the period 2002–2010 to explore the interaction between risks and the role of corporate governance. As main results, the authors found that CR, LR, and interest rate are interconnected. They also reported that corporate governance can be crucial in reducing this interaction.

In contrast to the above-mentioned positive correlation between CR and LR, few research have substantiated either the negative or the lack of a substantial influence between the two. Cai and Thakor (2008), for instance, looked at the connection between interbank competitiveness, LR, and CR. According to the authors, increased CR may lessen LR at a minor degree of competition. Imbierowicz and Rauch (2014) examined, using a sample of US commercial banks, the link between CR and LR between 1998 and 2010. Empirical findings show no significant effect between the two risks, but both significantly influence banks' probability of default. In a study conducted by Setiawan et al. (2021), a sample of 28 conventional banks in Indonesia was used to examine the influence of CR and LR on the probability of default and their reciprocal connection. Their findings indicated that CR reduced the probability of default. There is no reciprocal link between the two forms of risk.

To determine if the link between LR and non-performing loans (NPLs) has a threshold impact, the authors examined a sample of 33 banks from seven rising European nations between 2007 and 2016. The LTD ratio, which is a measure of LR, and non-performing loans have a non-linear connection, according to the PSTR model's results. More exactly, they identified 95% as the best LR threshold for their sample. It was also shown that when this threshold is exceeded, the NPLs ratio is more susceptible to changes in bank performance and ownership concentration.

Recently, following Pop et al. (2018), Boussaada et al. (2022), Imbierowicz and Rauch, (2014) tested the non-linear relationship between LR and NPL ratio for a sample of MENA banks. In addition to the LTD ratio used in the study of Pop et al. (2018); Boussaada et al. (2022) used the second measure of LR, which is the liquid assets to deposit and short-term funding (LADSF) ratio. Empirical findings of the PSTR model also indicate that there is a threshold effect in the LR- NPLs relationship for the MENA banks. The authors defined two optimal thresholds. Specifically, the LTD ratio is 73.10%, whereas the LADSF ratio is 87.61%. The authors discovered that LR and NPLs had a positive and significant correlation above the LTD ratio threshold of 73.10% and below the LADSF ratio threshold of 87.61%. Compared to the threshold of LR of 95% defined by Pop et al. (2018), that of Boussaada et al. (2022) is weaker. This means that the ratio of bank NPLs in the MENA region is more sensitive to LR than in European emerging countries. A non-linear link between CR, LR, and bank stability was studied by Djebali and Zaghdoudi (2020) using a sample of 75 banks from 11 MENA countries between 1999 and 2017. Confirming the non-linearity, the authors established a threshold of 13.16 and 19.03% for non-performing loans (NPLs) in relation to LR, which is determined by dividing liquid assets by total assets. The two risks' impact on bank stability varies depending on the regime, the authors discovered.

From the previous studies, we noted two remarks. First, all of them are focused either on linear or non-linear analysis. No study has explored this association within the two frameworks. Second, focusing on the non-linear relationship, all studies tested the issue in one direction, running from LR to CR (NPLs). No studies have tested the reverse relationship or the reciprocal relationship. All these considerations motivated us to explore this subject in two directions and a linear and non-linear methodology.

Data and empirical method

Data. We utilized a sample of Tunisian banks that were monitored between 2000 and 2018 in order to investigate the reciprocal link between LR and CR. Merely 10 identified banks that are deemed to be the most prominent in the Tunisian economy comprise the sample. Furthermore, they are listed top in terms of overall assets, total loans, and total deposits. Appendix 1 has a more detailed list of Tunisian banks. The data comes from two primary sources. Accounting and financial data are compiled from each bank's annual reports from the Tunisian Professional Banking and Financial Institution Association[2]. From the World Bank database[3] (WDI), macroeconomic variables are derived.

Variables and empirical methodology. We use two empirical methodologies since this study is based on both linear and non-linear analysis. The Seemingly Unrelated Regression (SUR) model is used in the first one to examine the linear relationship between credit and LR. The Panel Smooth Transition Regression (PSTR) model is used in the second to evaluate the possibility of a nonlinear link between the two risks.

As previously stated, we employ the SUR model, which was first put out by Zellner (1962) to investigate the reciprocal linear connection between LR and CR. The observable variables in the SUR model can be categorized as either exogenous (independent) or endogenous (dependent) variables. It is a system of many equations. The SUR approach offers for increased estimating efficiency when compared to fixed, random, and dynamic panel data estimation.

In banking literature (Cai and Zhang 2017; He and Xiong 2012; Gorton and Metrick 2012, Khan and Yilmaz 2022; Magwedere and Marozva 2022), CR and LR are considered reciprocal risks. In these empirical studies, LR is highly explained by CR and vice versa. For this reason, we used a system of multiple equations, more precisely, the SUR model based on two equations. The first equation relates to LR, and the second is devoted to CR.

To explain either LR or CR, we used some variables that have served previously to explain such relations. We introduce bank diversification (DIV) as an independent variable in the econometric models. Several empirical studies concluded that the effect of bank diversification on bank risk can be positive (Delpachitra and Lester 2013; Stiroh 2006b). We also included the ratio of equity to total assets (EQTA). A well-capitalized bank seems to be less sensitive to bank risks and shocks (Abreu and Mendes 2002; Boussaada and Hakimi 2021). We used bank size to assess whether large or small banks manage bank risks (Boussaada and Hakimi 2021; Pasiouras and Kosmidou 2007; Faiz 2022). As bank performance, we introduce a variable that measures the net interest margin (NIM). More profitable banks are less exposed to bank risks (Hamdi and Hakimi 2019). In banking literature, macroeconomic conditions are strongly used to explain either bank performance or bank risks (Boussaada and Hakimi 2021; Calza et al. 2003; Ghenimi et al. 2021; Faiz 2022). Hence, we include, the growth rate of gross domestic product (GDP) and the inflation rate (INF) in the econometric models. The two equations are given as follows:

$$\boldsymbol{LTD}_{i,t} = \boldsymbol{NPLs}_{i,t} + DIV_{i,t} + EQTA_{i,t} + SIZE_{i,t} + NIM_{i,t} + GDP_t + INF_t + \varepsilon_{i,t} \quad (1)$$

$$\boldsymbol{NPLs}_{i,t} = \boldsymbol{LTD}_{i,t} + DIV_{i,t} + EQTA_{i,t} + SIZE_{i,t} + NIM_{i,t} + GDP_t + INF_t + \varepsilon_{i,t} \quad (2)$$

We used a Panel Smooth Transition Regression (PSTR) model to evaluate the non-linear link between LR and CR. The PSTR model is a development of Hansen's (1999) PTR model. It indicates the ideal transition variable threshold that has an impact

on the dependent variable. The following Eq. (3) provides the PSTR model:

$$y_{i,t} = \mu_i + \beta_0' x_{i,t} + \beta_1' x_{i,t} g(q_{i,t}, \gamma, c) + \varepsilon_{i,t} \quad (3)$$

Where; i = 1, …, N, and t = 1, …, T,

The transition function may be represented as $g(q_{i,t}, \gamma, c)g$. The transition variable is denoted by (q_{it}), the optimum threshold by (C), and the smooth transition parameter by (γ). The logistic form of m orders in Eq. (4) has been proposed in accordance with [Granger and Teräsvirta, 1993; Jansen and Teräsvirta, 1996]:

$$g\left(q_{i,t}, \gamma, c\right) = \left[1 + \exp\left(-\gamma \prod_{j=1}^{m}\left(q_{i,t} - C_j\right)\right)\right]^{-1} \quad (4)$$

We have built the following nonlinear model in Eqs. (5), (6) to investigate the nonlinear link between CR and LR in Tunisia. The transition variable in Eq. (5) is LR (LTD), and the dependent variable is CR (NPLs).

Table 2 Statistical analysis.

Variable	Obs	Mean	Std. Dev.	Min	Max
Ltd	190	116.600	35.232	63.556	259.709
Npls	190	14.401	0.088	0.501	48.021
Div	190	2.295	1.017	0.001	8.683
eqta	190	9.018	3.083	0.297	17.482
size	190	14.987	1.009	7.609	16.577
Nim	190	2.624	1.020	0.443	5.926
gdp	190	3.247	1.959	−1.917	6.710
Inf	190	3.792	1.261	1.983	7.308

259.70% and a minimum value of 63.55%. CR measured by the ratio of NPLs records a mean value of 14.40%. From descriptive statistics, we conclude that some banks registered a high ratio of NPLs, with a maximum of 48.02% and other banks are less exposed to CR, with only a 0.50% as NPL ratio. Concerning bank

$$\begin{aligned} \boldsymbol{NPLs_{i,t}} = {} & \mu_i + \alpha NPLs_{i,t-1} + \beta_0^1 \boldsymbol{LTD} + \beta_0^2 DIV + \beta_0^3 EQTA_{i,t} + \beta_0^4 SIZE_{i,t} + \beta_0^5 NIM_{i,t} + \beta_0^6 GDPG_{i,t} + \beta_0^7 INF_{i,t} \\ & + \left[\beta_1^1 DIV_{i,t} + \beta_1^2 EQTA_{i,t} + \beta_1^3 SIZE_{i,t} + \beta_1^4 NIM_{i,t} + \beta_1^5 GDPG_{i,t} + \beta_1^6 INF_{i,t}\right] g\left(LTD_{i,t}, \gamma, c\right) + \varepsilon_{i,t} \end{aligned} \quad (5)$$

$$\begin{aligned} \boldsymbol{LTD_{i,t}} = {} & \mu_i + LTD_{i,t-1} + \beta_0^1 \boldsymbol{NPLs} + \beta_0^2 DIV + \beta_0^3 EQTA_{i,t} + \beta_0^4 SIZE_{i,t} + \beta_0^5 NIM_{i,t} + \beta_0^6 GDPG_{i,t} + \beta_0^7 INF_{i,t} \\ & + \left[\beta_1^1 DIV_{i,t} + \beta_1^2 EQTA_{i,t} + \beta_1^3 SIZE_{i,t} + + \beta_1^4 NIM_{i,t} + \beta_1^5 GDPG_{i,t} + \beta_1^6 INF_{i,t}\right] g\left(NPLs_{i,t}, \gamma, c\right) + \varepsilon_{i,t} \end{aligned} \quad (6)$$

Table 1 provides definitions and measurements for every variable.

Empirical findings

We initially provide a correlation matrix and descriptive statistics in the section on empirical findings. The outcomes of a linear analysis based on the SUR model are then shown and discussed. Finally, we go over the PSTR model's results.

Statistical analysis and correlation. Descriptive data for each variable utilized in this investigation are shown in Table 2. For every variable, we provide data on its mean, standard deviation, maximum, and lowest values, among other things. This allows for a better understanding of the macroeconomic environment in Tunisia as well as accounting and financial factors pertaining to the country's banking industry.

Table 2's statistics show that, as determined by the LTD ratio, the average value of LR is 116.6%, with a maximum value of

Table 1 Variable definitions and measurements.

Variables	Definition	Measurement
Dependent variables		
NPLs	Bank nonperforming loans	Bank nonperforming loans to gross loans (%)
LIQR	LR	Loans to deposits ratio (%)
Bank Specifics		
DIV	Bank diversification	Noninterest income ratio
CAP	Bank capital	Equity to total assets ratio
SIZE	Bank size	The Napierian logarithm of total assets
NIM	Bank performance	Net interest margin ratio
Macroeconomic Specifics		
GDPG	Economic growth	The annual growth rate of Gross Domestic Product (%)
INF	Inflation rate	Consumer price index (%)

capital, the capital adequacy ratio indicates a mean value of 9.01%.

While certain Tunisian banks have a maximum capital ratio of 17.48%, descriptive statistics reveal that other banks have lower capital ratios, as low as 0.29%. Despite this, several banks in the country are nonetheless well capitalized. We calculate the Napierian logarithm of total assets to determine bank size. The average bank size is 14.98. The average number for bank performance is around 2.62%. The more lucrative bank reports a net interest margin ratio of 5.92%, whilst the less profitable bank reports a ratio of 0.44%.

When looking at macroeconomic statistics, the GDP growth has a mean value of 3.24% and a high growth rate of 6.4% from 2000 to 2018. The inflation rate is the second major factor in the economy. The high rate of inflation is almost 7.3%, while the average is 3.79%. The degree of correlation between the study's variables is displayed in Table 3. To look for multicollinearity, we employed the Pearson correlation. We may infer from Table 3 that there is very little connection between the independent variables. This verifies that there isn't a multicollinearity issue.

Results of linear analysis: a SUR model. Before performing the SUR method, one of the necessary conditions is the disturbances correlation. Hence, we should first check the residuals of the correlation for the two equations relative to credit and LRs.

The results of the Breusch-Pagan test and the residuals correlation matrix are shown in Table 4. The residuals in the two equations for CR and LR have a correlation that deviates from zero, as Table 4 demonstrates. As a result, we may accept that the residuals of the two equations are linked and reject the hypothesis that this correlation is zero. A residual association is also shown by the Breusch-Pagan test. We found that the test's probabilities equal 0.021, which validates the relationship between the two equations' residuals and is significant at the 5% level.

Table 3 Correlation matrix.

	Ltd	Npls	Div	Eqta	Size	Nim	Gdp	Inf
Ltd	1.0000							
Npls	0.0646	1.0000						
	0.3758							
Div	0.1711*	0.2385*	1.0000					
	0.0183	0.0009						
Eqta	0.2529*	−0.0412	0.0730	1.0000				
	0.0004	0.5720	0.3171					
Size	−0.1762*	0.1311	−0.0527	0.0075	1.0000			
	0.0150	0.0715	0.4703	0.9186				
Nim	−0.0839	0.0100	−0.1104	0.1987*	−0.1622*	1.0000		
	0.2499	0.8913	0.1296	0.0060	0.0254			
Gdp	0.2345*	−0.2990*	−0.0049	0.1213	−0.2494*	0.1942*	1.0000	
	0.0011	0.0000	0.9463	0.0954	0.0005	0.0073		
Inf	−0.0467	0.3839*	0.1623*	−0.1320	0.3077*	−0.3254*	−0.1998*	1.0000
	0.5221	0.0000	0.0253	0.0694	0.0000	0.0000	0.0057	

Table 4 Correlation matrix of residuals.

	Ltd	Npls
Ltd	1.0000	
Npls	0.1673	1.0000
Breusch-Pagan test of independence:		
	chi2(1)	Prob
	5.319	0.021

Table 5 Findings of the SUR model.

	Coef.	Std. Err.	Z	P > z
Eq. (1) *dependent variable is LR (LTD)*				
NPLs	1.297	0.281	4.610	0.000***
Div	0.020	0.024	0.820	0.410
Eqta	−2.996	0.769	−3.900	0.000***
Size	−0.052	0.025	−2.100	0.036**
Nim	−8.898	2.495	−3.570	0.000***
Gdp	−0.053	0.013	−4.110	0.000***
Inf	0.037	0.022	1.720	0.086*
_cons	0.827	0.424	1.950	0.051
Eq. (2) *dependent variable is CR (NPLs)*				
Ltd	0.082	0.018	4.610	0.000***
Div	0.023	0.027	0.851	0.393
Eqta	−0.290	0.200	−1.450	0.147
Size	−0.004	0.006	−0.640	0.521
Nim	−2.413	0.623	−3.870	0.000***
Gdp	−0.016	0.003	−4.940	0.000***
Inf	0.027	0.005	5.330	0.000***
_cons	0.494	0.101	4.890	0.000***

Equation	RMSE	R-sq	chi2	*P*
Lrisk	0.319	0.1785	63.05	0.000
Crisk	0.080	0.2712	93.23	0.000

Significant levels at 1%, 5% and 10% are indicated by the symbols ***, ** and *, respectively.

We are able to run the SUR model because the disturbances connection between the two equations has been verified. In Table 5, empirical results are shown. In the first equation, CR has a large influence on LR (NPLs→LTD), with the exception of bank diversification. The only factors that appear to have no discernible impact on the second equation, which evaluates the opposite effect (LTD→NPLs), are bank size, bank capitalization, and bank diversification. Simultaneously, the other factors have a 1% influence.

NPLs and LTD have a positive and substantial correlation, according to the results shown in Table 5. The bank's LR level is considerably raised by a high CR ratio. This outcome is comparable to that of Acharya and Viswanathan (2011); He and Xiong (2012); Boussaada et al. (2022), and Boussaada et al. (2022). Results also show that bank NPL levels are considerably reduced by a high capital ratio (EQTA). The NPLs ratio drops by 2.99% for every 1% rise of the equity to total assets ratio. Greater capitalization allows banks to control and hedge their CR. Furthermore, risk-taking and speculative bank behavior are decreased by high bank capital ratios. There are no incentives to provide loans with insufficient guarantees, which result in the loss of principle and interest. This result agrees with the findings of Boussaada et al. (2022).

Bank size has a large and detrimental influence on non-performing loans (NPLs), much like the effect of bank capital does. Large banks are able to handle their LR well and are quite liquid. Furthermore, we discovered that banks with higher profitability have lower exposure to leverage ratios. The findings show that LR drops by 8.89% for every 1% rise in the net interest margin. Numerous factual research contend that prosperous and sizable banks are less vulnerable to credit and loss ratios. Bank risk management is something that larger, more successful institutions have mastered. These banks also have enough capital to hedge bank risks during banking fragilities and crises, making them less vulnerable to bank risks and shocks.

The findings indicate that LR decreases under macroeconomic conditions characterized by rapid GDP growth and low inflation. It was discovered that the LR ratio drops by 0.05% with every 1% increase in GDP. By comparison, a 1% rise in the rate of inflation results in a 0.03% rise in the LTD ratio. Increases in borrower solvency and loan repayment likelihood lower NPL levels and, in turn, lower bank lending ratios during times of economic boom. This result supports the findings of Calza et al. (2003). Conversely, during an inflationary period—particularly when inflation is unanticipated—a high rate of inflation results in a high interest rate, which raises borrowers' operating and financial costs and renders them unable of repaying their debts. In this instance, LR rises in proportion to the number of NPLs. Abreu and Mendes' (2002) findings are comparable to this one.

Table 6 Linearity test.

Transition variables	*LTD*		*NPLs*	
Tests	**Statistics**	***P* value**	**Statistics**	***P* value**
Lagrange Multiplier Wald Test	13.795	0.049**	23.181	0.001***
Lagrange Multiplier F-Test	1.934	0.036**	3.434	0.001***
Likelihood-ratio Test	14.321	0.045**	24.721	0.000***

Significant levels at 1 and 5% are indicated by the symbols *** and **, respectively.

Empirical evidence supports the reciprocal link between the two dangers, as the second equation's results (LTD→NPLs) demonstrate. The reciprocal association in reverse between the LTD and NPL ratios was also verified. By 0.08%, the level of NPLs ratio rises with a 1% increase in the LR. Similar to how LR is impacted, we also discovered a negative and substantial correlation between bank performance and CR. In other words, banks with more profits are less vulnerable to CR. For the equation of CR, the similar impact of macroeconomic circumstances was verified. Findings indicate a substantial negative correlation between the ratio of non-performing loans and higher GDP growth. In Tunisia, however, the amount of CR rises in direct proportion to the growth in the inflation rate.

Findings of non-linear analysis: a PSTR model

Results of the pre-tests. Certain preliminary conditions need to be verified before the PSTR model is tested. The first stage is to determine if correlations between CR and LR are linear as the PSTR model implies that there is a non-linear relationship between the dependant and transition variables. We employed the Lagrange Multiplier (Wald test), the Lagrange Multiplier (F-test), and the Likelihood-ratio test (LR) to ensure linearity. The null hypothesis is that $H_0{:}\beta_1 = 0$ and the alternative is H *that does* $_1{:}\beta_1 \neq 0H$. The results of the three tests are summarized in Table 6.

When LR (LTD) is the dependent variable in all three tests, the null hypothesis is rejected at the 5% level; when CR (NPLs) is the dependent variable, it is rejected at the 1% level. The nonlinearity of the reciprocal relationship between CR and LR is confirmed by these figures.

Finding the number of regimes is the second phase, which is carried out once the non-linearity between the dependent and transition variables is verified. With the use of this test, it will be possible to determine if the PSTR model contains at least two transition functions (m = 2) or just one (m = 1), which would indicate an alternate hypothesis. To get this conclusion, statistics from the LMw and LMF tests are consulted. Table 7 displays the test results for the number of regimens.

Based on Table 7, we deduce that, for both tests, the hypothesis with at least two thresholds (r = 2) and the hypothesis without a threshold (r = 0) are rejected at the 1% significant level. As a result, we concede that the model has a single threshold and reject the null hypothesis, recognizing the existence of at least two transition functions.

Assume that the rejection of linearity is the PSTR model's beginning condition. In that situation, the primary goal of this econometric technique is to determine the best threshold for the transition variable that influences the dependent variable. Therefore, the best levels of LR and CR are determined in the next stage.

Since the LR and CR are recognized as reciprocal risks, we aim to define two thresholds. The first is devoted to LR, and the second is related to CR.

Table 7 Test of the number of regimes.

Transition variables		**LTD**		**NPLs**	
Hypotheses	**Tests**	**Statistics**	***P* value**	**Statistics**	***P* value**
(1) H_0: r = 0; H_1: r = 1	LRT	24.688	0.037**	62.133	0.000***
	F	1.984	0.021**	6.445	0.000***
(2) H_0: r = 1; H_1: r = 2	LRT	93.556	0.000***	88.093	0.000***
	F	6.305	0.000***	5.619	0.000***

Significant levels at 1 and 5% are indicated by the symbols *** and **, respectively.

Table 8 Results of threshold values.

	LTD→NPLs	**NPLs→LTD**
γ	0.900	1.4
C	**102%**	**9.87%**
AIC	−5.748	−2.465
BIC	−5.475	−2.191

The findings presented in Table 8 suggest that 102% is the ideal level of LR that influences CR. We deduce that this criterion is lower than the mean value when we compare it to the average value of 116.6%4[4]. This implies that by having a loan-to-deposit ratio that is almost 100%, Tunisian banks are asked to manage and lower this risk. The circular of the Central Bank of Tunisia n° 2018-105[5] in article two requires that the loan-to-deposit ratio should not exceed 120%. Based on the threshold defined, the Tunisian central bank should revise the LTD ratio to be only 100%.

Concerning the CR threshold, Table 8 shows that the optimal threshold of NPLs ratio is 9.87%. This threshold seems lower than the mean value of 14.4%. This leads to the conclusion that Tunisian banks should make great effort to reduce the level of NPLs ratio.

In terms of the PSTR model's stability, Ibarra and Trupkin (2011) noted that the PSTR model is seen as having two regimes if γ is extremely high. It is best to use the PTR model. Nonetheless, the PSTR model is the best suitable when the γ is extremely low. Table 8 demonstrates that the first model connected to LR has a positive smooth parameter γ of 0.9, whereas the second model associated to CR has a positive smooth parameter γ of 1.4. The stability of the PSTR model is shown by the smooth parameter's weak value.

Results of the PSTR model. Empirical results of the reciprocal non-linear relationship between LR and CR are given in Table 9. Columns 1 and 2 present the results of the threshold effect of LR on CR. Columns 3 and 4 inform about the non-linear effect of CR on LR for Tunisian banks.

Under the optimum thresholds, the reciprocal connection between credit and LR is negative and significant at the 1% level, according to empirical evidence presented in Table 9. Exceeding these ideal benchmarks, on the other hand, results in a positive effect that is only noteworthy when considering the impact of CR on LR. In other words, with an LTD ratio below 102% and an NPLs ratio less than 9.87%, the reciprocal relationship between the two risks is negative and significant at 1%. However, surpassing these two optimal thresholds, only CR causes a significant increase in LR. In this case, Tunisian banks are invited

Table 9 The PSTR model's estimate results.

	LTD→NPLs		NPLs→LTD	
Variable	**Coeff**	**T-Stat**	**Coeff**	**T-Stat**
DIV	0.027	0.904	0.016	0.139
EQTA	−5.204	−2.526**	−0.688	−3.355***
SIZE	−0.021	−0.470	−0.008	−1.437
NIM	−3.063	−5.408***	−1.195	−1.936*
GDP	−0.087	−3.461***	−0.005	−1.944*
INF	0.011	2.624***	0.027	0.402
LTD < 102%	−2.524	−2.727***	—	—
LTD > 102%	1.323	1.333	—	—
NPLs < 9.87%	—	—	−0.440	−8.128***
NPLs > 9.87%	—	—	0.442	7.066***
γ	0.900		1.400	
C	102%		9.87%	
Obs	190		190	

Significant levels at 1%, 5% and 10% are indicated by the symbols ***, ** and *, respectively.

to maintain the LTD ratio below 102% and the NPLs ratio less than 9.87% with more attention to the CR since it is above the optimal threshold; it significantly increases the LR. Some reforms have been made regarding the LR measured by the LTD ratio. The circular of the Central Bank of Tunisia n° 2018-10 in article two requires that the loan-to-deposit ratio should not exceed 120%. However, we think the Tunisian central bank should go less than 120% based on the threshold of 102%. Concerning CR, Tunisian banks are invited to reduce their NPLs to less than 9.87% by reducing asymmetric information, requiring sufficient guarantees, and implementing efficient methods and strategies for hedging and managing this risk.

Findings also indicate that the ratio of equity to total assets, bank performance, and GDP growth negatively and significantly affect both LR and CR. However, no significant effect of bank size and bank diversification was found. Finally, inflation exerts a positive and significant effect only on CR.

Based on the results in Table 9, the ratio of equity to total assets (EQTA) exerts a negative and significant effect on both credit and LR. We found that an increase of 1% in bank capital reduces CR by 5.2% and LR by 0.68%. Generally, well-capitalized banks are more profitable. Hence, they are not motivated to adopt speculative behavior and to grant "*bad loans*" without sufficient guarantees. Furthermore, banks with high capital ratios can well hedge and manage either credit or LRs. Results also show that more profitable banks are less exposed to credit and LRs. An increase of 1% in the net interest margin decreases CR by 3.06% and LR by 1.19%.

In relation to the impact of macroeconomic conditions, we discovered a negative and substantial correlation between the GDP growth rate and both credit and LRs. The inflation variable has no discernible impact on LR and only has a positive and substantial correlation with credit. For the linear analysis, the same outcome was discovered and examined.

Conclusion and policy recommendations

Contrary to Boussaada et al. (2022) and Pop et al. (2018), who only tested the non-linear relationship between LR and NPLs in one causal direction, this study addresses the complex relationship between NPLs and LTD ratios in the two causal directions and a linear and non-linear framework.

We examined data on Tunisian banks from 2000 to 2018 and applied two empirical methodologies. The first one explores the linear relationship. Since credit and LR are recognized as causal and complex risks, we performed a SUR model. The second one is based on a non-linear model. To be more specific, we applied the PSTR model.

Both for linear and non-linear analyses, findings indicate that bank specifics, bank capital ratio, bank size, and bank performance are the main factors that significantly contribute to a reduction of both NPLs and LTD ratios. At the same time, bank diversification measured by the non-interest income was found without significant effect. We found that GDP growth significantly decreases credit and LR. In contrast, the inflation rate exerts a positive and significant impact on the NPLs ratio.

For the non-linear analysis, the results from the PSTR model suggest the presence of a threshold effect for both NPLs→ LR and LR → NPLs relationships. More precisely, we found that the threshold of the NPLs ratio (CR) is 9.87%, while the threshold of the LTD ratio (liquidity riks) is 102%. We also found below the optimal thresholds, the linkage between NPLs and LTD is negative and significant at the 1% level of significance. However, above these optimal thresholds, the effect becomes positive and significant only significant for the NPLs →LTD relationship.

The results presented in this study may hold significant policy implications for banks in Tunisia. The first is relative to the causal linkage between LR and CR. Based on the optimal thresholds defined, Tunisian banks should maintain a ratio of NPLs lower than 9.87% to avoid negative implications. About the threshold of LTD ratio, as a recommendation for the Tunisian Central Bank in its circular of n° 2018-10, more precisely in article 2, the LTD ratio of 120% should be revised to only 100% to be less than the defined threshold of the PSTR model of 102%. The second recommendation is relative to the impact of bank specifics. Since, capital, size, and performance decrease both credit and LR, great importance should be placed on these factors to reduce the two major risks. Hence, Tunisian banks are recommended to strengthen their bank capital ratio. Regarding bank size, merger and acquisition operations could be beneficial. Additionally, Tunisian banks should implement and follow some strategies to increase their profitability and be less sensitive to bank risks and shocks. The last one is devoted to the macroeconomic environment. Significant work should be done by the Tunisian government to stabilize macroeconomic conditions. Macroeconomic factors can have a considerable impact on the risk or performance of the Tunisian banking sector, which is one of the most active sectors in Tunisian economy finance.

Although this study addresses some interesting policy implications, it has some limitations. For example, the sample was limited to 10 banks, which limited the generalization of the results. Second, we used the loans-to-deposits ratio to assess LR.

The results of the study might be enhanced, nonetheless, by the liquidity coverage ratio (LCR) and net stable funding ratio (NSFR).Hence, as future research, increasing the sample size by including other Tunisian banks and utilizing additional proxies for LR, such as LCR and NSFR, may lead to more robust results.

Data availability

The datasets analyzed during the current study are available in the Dataverse repository: https://doi.org/10.7910/DVN/QAKA0N.

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Notes

1 For more details, see statistics relative to Tunisia country in the World Development Indicators (WDI) database.
2 https://www.apbt.org.tn/.
3 http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators&preview=on.
4 See descriptive statistics in Table 2.
5 For more details, see the circular of the Central Bank of Tunisia n° 2018-10.

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Author contributions

JB and AH conceptualized the study, obtained the data, conducted the data analysis and drafted the paper. AH and TZ contributed to the model development and results interpretation. KT contributed to the literature review, the formation and compilation of conclusion. All authors read and approved the final manuscript.

Competing interests

The authors declare no competing interests

Ethical approval

This article does not contain any studies with human participants performed by any of the authors.

Informed consent

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