

The impact of climate change on credit portfolios and banking resilience: Preliminary evidence from a developing economy

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ABSTRACT

This study investigates the impact of climate change on credit portfolios and banking resilience in Pakistan, a developing economy with significant exposure to environmental risks. We employ a stress-testing methodology to evaluate the effects of various climate change scenarios on banking firms, ranging from low to high emissions. Specifically, using data from 2011 to 2022, we assess the credit exposure of key sectors by linking macroeconomic variables such as GDP growth and temperature changes to credit infections and the probability of default. Our findings reveal that rising temperatures significantly increase financial vulnerabilities, leading to a notable degradation of asset quality and an increase in default likelihood. Due to its reliance on water-intensive processes, the textile sector is particularly prone to climate-induced disruptions, resulting in higher default risks. These results highlight the importance of integrating climate risk assessments into banking practices, focusing on sector-specific strategies to enhance financial stability.

Introduction

Climate change has emerged as a critical risk factor for economies worldwide (Fan & Gao, 2024). Over the years, the steady rise in global temperatures has been linked to increasing greenhouse gas emissions and widespread environmental degradation (Mirza, Umar, Horobet, & Boubaker, 2024). Over the past century, human activities such as industrialization, deforestation, and burning fossil fuels have significantly elevated the concentration of greenhouse gases. These emissions create a “greenhouse effect,” trapping heat and leading to a consistent rise in global temperatures. This warming has accelerated environmental degradation, contributing to biodiversity loss as ecosystems struggle to adapt to rapidly changing conditions (Zhao, Wang, Stan, & Mirza, 2024).

While the effects are evident across various sectors, the financial industry, particularly the banking sector, encounters distinct and complex challenges in managing the risks posed by climate change (Mirza, Umar, Sbiba, & Jasmina, 2024). Unlike other industries, banks act as crucial economic intermediaries, providing essential services such as lending, investment, and risk management. This role exposes them to a broad spectrum of climate-related risks, including physical hazards, such as damage to assets from extreme weather events, and transition risks linked to the global shift toward a low-carbon economy (Rahat & Nguyen, 2023).

These risks can adversely impact the creditworthiness of borrowers, the value of collateral, and the stability of investment portfolios, leading to greater volatility in financial markets (Shan, Mirza, Umar, & Has-naoui, 2023). Besides, traditional risk management frameworks in banks were not initially designed to address the long-term, uncertain, and potentially severe impacts of climate change, necessitating the development of new tools and strategies (Afzal, Hasnaoui, Firdousi, & Noor, 2024). Banks must also adapt to evolving regulatory demands and increasing market expectations for transparency and accountability in managing climate-related financial risks (Lv, Mirza, Umar, & Chen, 2023). As a result, the banking sector must not only safeguard its balance sheets but also play a pivotal role in enhancing the overall resilience of the financial system in the face of growing climate challenges. In developing economies, where financial systems are often more fragile and less capable of absorbing shocks, the impact of climate change is particularly severe (Ali, Naveed, Al-Nassar, & Mirza, 2024).

These economies typically face structural challenges, such as weaker regulatory frameworks, limited access to capital, and less diversified economies, all increasing their exposure to climate risks (Rahman, Misra, & Tiwari, 2024). As a result, the banking sector in these regions is highly vulnerable to the ripple effects of environmental disruptions.

Environmental risks and financial stability are now key concerns. Extreme weather events damage infrastructure, disrupt economies, and result in financial losses. Rising temperatures and shifting climate patterns exacerbate challenges in critical sectors such as agriculture, water, and energy, which are vital to the economic health of developing countries. These factors directly impact borrower creditworthiness as businesses and individuals

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face increasing difficulties in maintaining operations, repaying loans, and generating income. As a result, the stability of credit portfolios in these economies is at greater risk. Banks may experience an increase in non-performing loans (NPLs) as more borrowers default on their obligations, potentially destabilizing financial institutions. This risk is amplified because many banks in developing economies lack the advanced risk management tools and capital reserves to mitigate these threats effectively (Xie, Mirza, Umar, & Ji, 2024). Therefore, addressing the nexus between climate change and financial stability is essential, requiring proactive measures from policymakers, regulators, and financial institutions to enhance resilience in the face of growing climate challenges.

This paper examines the impact of climate change on credit portfolios and banking resilience in a developing economy. While much of the existing literature focuses on financial stability, most studies rely on ex-post data (for example, Fan and Gao (2024) and Mirza, Umar, Horobet, and Boubaker (2024)), which captures historical impacts but lacks predictive insight for future risks. Our study fills this gap by offering preliminary evidence from a developing economy with unique vulnerabilities and adaptation challenges. A key aspect of our methodology is stress testing, a tool commonly used in developed economies to assess financial resilience. Unlike ex-post approaches, stress testing enables us to evaluate the potential future impacts of climate change on banking systems. Given the limited data and less robust financial systems in developing economies, our stress testing application represents a novel approach.

The rest of the paper is organized as follows. Section 2 presents the salient features of the banking sector in Pakistan, section 3 presents our empirical strategy, results are discussed in section 4, and section 5 concludes.

Banking sector of Pakistan

The banking sector in Pakistan plays a critical role in the country's financial system, serving as the primary channel for capital allocation, financial intermediation, and economic development. Over the years, this sector has undergone significant transformation, shaped by various economic, regulatory, and technological changes (Saeed, Kamran, Thanakijombot, & Manita, 2024). Pakistan's banking sector predominantly comprises commercial banks, including public and private sector banks, specialized banks, development finance institutions (DFIs), Islamic banks, microfinance banks, and foreign banks. There are over 30 large, mid-sized, and small commercial banks. The sector is highly concentrated, with a few large banks holding a significant share of total assets, deposits, and advances.

The State Bank of Pakistan (SBP), the country's central bank, regulates the banking sector and plays a pivotal role in ensuring financial system stability, overseeing monetary policy, and maintaining an efficient payment system. The SBP's regulatory framework aligns with international standards and covers capital adequacy, liquidity management, credit risk, and corporate governance.

(Ghulam & Dhruva, 2024) noted that the banking sector in Pakistan has evolved significantly in recent decades. In the 1990s, the industry experienced privatization and liberalization, leading to increased competition and efficiency. Similar trends were observed in other emerging economies, where privatization catalyzed growth and stability (Tovar Jalles, Park, & Qureshi, 2024). However, while many developing countries saw rapid financial sector liberalization leading to growth, Pakistan faced a unique challenge in integrating with global markets due to political instability and economic volatility, factors less prevalent in other regions (Shaikh, Glavee-Geo, & Karjalainen, 2017).

The banking sector saw rapid growth in the 2000s, driven by economic expansion, financial sector reforms, and improvements in the regulatory environment. Technological advancements and the expansion of branch networks contributed to this growth. Compared to other developing economies, Pakistan's financial inclusion efforts lagged, particularly in rural areas, where access to banking remains limited. This trend mirrors findings in countries like India, where financial inclusion has remained challenging despite similar reform efforts (Pradhan, Arvin, Nair, Hall, & Bennett, 2021).

While Pakistan's banking sector has grown more resilient with stronger capital adequacy and reduced non-performing loans (NPLs), concerns remain, particularly within specific segments (Mirza, Rahat, & Reddy, 2015). The rise of Islamic banking has been another key trend in Pakistan, similar to what has been seen in other Muslim-majority countries like Malaysia, where Islamic banking has become a significant part of the financial landscape (Mensi, Hammoudeh, Tiwari, & Al-Yahyaee, 2020). However, despite the growth of Islamic banking, Pakistan still faces substantial exposure to climate-related risks, particularly in the agriculture sector, which is a major borrower from banks. This exposure presents a challenge shared with other countries, such as Sri Lanka, where agricultural lending also faces growing risks due to climate change (Abeysekara, Siriwardana, & Meng, 2023).

Moreover, Pakistan's banking sector faces systemic challenges, including economic instability, political uncertainty, and high credit concentration in textiles, agriculture, and energy sectors. These challenges are echoed in similar emerging economies, where overexposure to specific sectors has heightened risk profiles (Barón & Rodríguez, 2024). The reliance on traditional banking models further hampers financial inclusion, as it limits access to banking services in underserved regions and among low-income groups (Elgharib, 2024). This issue is not unique to Pakistan, as similar patterns of financial exclusion are seen in other developing economies, where digital banking and fintech innovations have yet to reach broader populations (Wang & Zhang, 2025). Lastly, as climate change increasingly impacts agriculture, the banking industry must integrate climate risk assessments into its lending practices. This trend is emerging in global financial sectors, but Pakistan faces particular challenges due to its heavy reliance on agriculture and vulnerability to climate risks. Comparatively, countries like South Africa and India have made strides in incorporating climate risk into financial decision-making, though the pace of integration remains slow (Saqib, Hussain, & Mefteh-Wali, 2024). Table 1 presents some key statistics of the banking sector, while Table 2 highlights the sectoral concentration of the loan portfolio.

The low level of financial inclusion remains a persistent challenge, with a large segment of the population still unbanked or underbanked. Despite efforts to expand banking services, access to formal financial services is limited in rural areas and among low-income groups. The sector's reliance on traditional banking models, combined with regulatory and infrastructural limitations, hampers the pace of financial inclusion. Another challenge is the exposure to climate-related risks, as climate change increasingly affects the agriculture sector, a major borrower from banks. The industry must integrate climate risk assessments into its lending practices to effectively manage potential future disruptions.

Research methodology and data

To assess the impact of climate change on credit portfolios in Pakistan, we consider the credit exposure of twenty-four scheduled banks. The exposure is broadly extended across nine sectors: textile,

Table 1

Key Financial Soundness Indicators of Pakistan's Banking Sector (in Percent).

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Capital Adequacy Ratio	15.6	14.9	17.1	17.3	16.2	15.8	16.2	17.0	18.6	16.7	17.0
Capital to Total Assets	9.0	9.0	10.0	8.4	7.8	7.1	7.1	7.2	7.2	6.3	5.9
NPLs to Loans (Gross)	14.6	13.3	12.3	11.4	10.1	8.4	8.0	8.6	9.2	7.9	7.3
Net NPLs to Net Loans	4.6	3.4	2.7	1.9	1.6	1.2	1.4	1.7	1.2	0.7	0.8
ROA (Before Tax)	2.0	1.6	2.2	2.5	2.1	1.6	1.3	1.5	1.8	1.6	2.1
ROE (Before Tax)	21.2	17.9	24.3	25.8	23.9	19.5	17.4	20.1	23.2	24.0	35.3
Liquid Assets/ Total Deposits	64.4	61.3	64.5	73.3	72.1	76.1	67.2	68.4	74.3	76.7	86.4
Advances to Deposit Ratio	52.2	49.5	48.2	46.4	46.6	50.1	55.8	51.7	44.8	46.6	50.4

Source: State Bank of Pakistan (<https://www.sbp.org.pk/ecodata/fsi.asp>).

food, beverages & tobacco, oil & gas, pharmaceuticals, chemicals, automobiles, fertilizers, electronics, and paper & board. These sectors are the major contributors to the country's GDP and represent significant borrowers' profiles (Afzal, Mirza, & Arshad, 2021). In general, stress testing is based on a three-step methodology (Foglia, 2018). This includes a macro model specification that links selected macro variables with the stress drivers. The second step is to calibrate a loan quality measure (NPL), through macroeconomic factors and stress factors. The last step is to create stress scenarios and assess their impact on credit exposures. In the first instance, we specify the following macro model

$$y_t = a + \beta_1 Temp_t + \beta_2 Temp_t^2 + \sum_{x=1}^m \gamma_x y_{t-x} + \varepsilon_t \quad (1)$$

Where y_t corresponds to two macroeconomic factors of GDP growth $\ln(gdp)_t$ and system-wide credit growth $\ln(cg)_t$. The variable $Temp_t$ refers to the variation in average temperature and we use both linear and quadratic specification. The link between climate change and macroeconomic variables is well documented by studies like (Kahn et al., 2021; Karydas & Xepapadeas, 2022; Rizvi, Naqvi, Boubaker, & Mirza, 2022) and forms the basis for our assessment. The GDP growth rate is related to credit infections as variations in business cycles lead to changes in repayment capacity (Cincinelli & Piatti, 2021). Similarly, a reduction in loan supply can trigger recessionary pressures, resulting in lower asset quality (Hasnaoui & Hasnaoui, 2022).

The next step is to relate these macroeconomic factors with the bank-specific factors. For this, we employ the following dynamic panel estimation.

$$\ln \left(\frac{NPL_{i,t}}{1 - NPL_{i,t}} \right) = \rho_i + c_i + \alpha \ln \left(\frac{NPL_{i,t-1}}{1 - NPL_{i,t-1}} \right) + \sum_{x=0}^m \mu_{i-x} \partial \ln(gdp)_{t-x} + \sum_{x=0}^m \tau_{i-x} \partial \ln(cr)_{t-x} + \varepsilon_{i,t} \quad (2)$$

This representation assumes that the logit (transformed) credit infections follow an autoregressive process AR(1). These are conditional on past economic (gdp) and credit growth (cg) with as many as m lags. In eq. 2, α is likely to be between 0 and 1, while both μ and τ will be negative, and ρ_i and c_i represent firm and country fixed effects. The idiosyncratic errors are captured by $\varepsilon_{i,t}$.

GDP growth is a key indicator of economic health and stability. It shapes the environment in which banks operate and affects credit demand, loan repayment, and financial performance (Saiz-Sepúlveda & Hernández-Tamurejo, 2024). Climate change can disrupt economic activity, particularly in sectors vulnerable to extreme weather. As a result, GDP growth is crucial for linking environmental risks to financial risks in the banking sector. Temperature changes, with their well-established impact on agriculture, energy, and water resources, are especially important in developing economies. These sectors are highly sensitive to climate variability, and their performance directly influences borrower creditworthiness. While other indicators, such as inflation or exchange

Forecast accuracy

To establish the accuracy of specifications 1 and 2, we forecast "in sample" NPLs for 2022. The data employed for this span from 1Q11 to 4Q22. The forecasted values are compared with actual NPLs for the period using mean squared error (MSE), root mean square error (RMSE), mean absolute percentage error (MAPE), and mean absolute error (MAE). These statistics are standardized measures and have been used previously in studies like (Mirza, Rahat, Naqvi, & Rizvi, 2020) to ascertain forecast accuracy. We take 4Q22 as our terminal quarter and exclude 2023 from the data owing to a significant increase in interest rates throughout 2023.

Temperature-driven stress scenarios

For this research, we use four climate change scenarios. The first is low emissions (LE), which will restrict temperatures below 2 °C. The next one is moderately low emissions (MLE) which assumes global warming up to 2.4 °C. Thereafter, we assume moderately high emissions with temperatures increasing by about 2.8 °C and, finally, a high emissions scenario with temperature change as high as 4.3 °C. These forecast scenarios are developed by The World Bank and forecasts for up till 2100 are available on the climate change knowledge portal.¹ Fig. 1 presents these forecasts

Measuring the impact of climate change on bank resilience

We employ two measures to assess climate change's impact on banking resilience. These include the probability of default and capital adequacy ratio (CAR). PD reflects on the risk profile, while CAR approximates the risk absorption capacity. Previous studies like

rates, offer insights into financial health, we prioritized GDP growth and temperature changes for their strong connection to climate-related disruptions.

(Boubaker, Nguyen, Trinh, & Vu, 2023), (Jin, Liu, Zhang, & Zhao, 2022), (Chen, Mirza, Huang, & Umar, 2022), (Yu, Li, Mirza, & Umar, 2022), and (Umar, Ji, Mirza, & Naqvi, 2021) have extensively documented the relevance of the likelihood of default and capital adequacy for banking well-being. For PDs, we employ the framework of (Hardy & Schmieder, 2013). Based on the scenario-based NPLs from Eq. 2, PD will be estimated as

$$PD_{it} = NPL_{it+1} - NPL_{it} + z \times NPL_{it-1}, \quad (3)$$

where z represents the loans that are written off in $t - 1$. Based on the arguments by (Misra, Rahman, & Tiwari, 2023), we set z at 0.25, which implies that loan write-off takes approximately four years. The data for this research is extracted from multiple sources, including Eikon, Bank Focus, State Bank of Pakistan, and the individual websites of the banking firms.

¹ The data and methodology is available at <https://climateknowledgeportal.worldbank.org/>

Table 2

The sector-wise exposure of the Banking Sector in Pakistan (Values in Billions PKR, ratio in Percent).

Sectors	2012			2013			2014			2015			2016			2017		
	Advances	NPLs	IR	Advances	NPLs	IR	Advances	NPLs	IR	Advances	NPLs	IR	Advances	NPLs	IR	Advances	NPLs	IR
Agribusiness	354.34	32.34	9.1	340.34	34.71	10.2	393.87	37.12	9.4	473.85	40.31	8.5	548.10	41.71	7.6	523.44	41.39	6.6
Automobile/Transportation	56.33	11.14	19.8	60.79	10.47	17.2	72.27	9.56	13.2	53.31	12.33	23.1	95.29	12.60	13.2	88.71	12.03	11.1
Cement	58.35	17.11	29.3	54.68	13.83	25.3	45.63	8.91	19.5	57.62	7.36	12.8	71.72	6.79	9.5	89.56	6.47	5.9
Chemical & Pharmaceuticals	150.10	14.91	9.9	150.26	13.44	8.9	190.39	16.19	8.5	223.61	13.52	6.0	250.09	12.78	5.1	236.95	12.86	5.4
Electronics	57.00	23.89	41.9	58.88	24.29	41.3	65.87	11.01	16.7	81.16	10.46	12.9	78.17	13.33	17.0	97.80	12.50	12.8
Financial	81.73	8.55	10.5	121.01	8.26	6.8	125.25	7.60	6.1	148.14	9.60	6.5	182.66	10.54	5.8	172.69	8.78	5.1
Individuals	333.31	54.11	16.2	383.16	47.09	12.3	432.84	53.29	12.3	454.62	45.78	10.1	550.38	58.03	10.5	518.88	54.73	8.8
Insurance	0.34	0.00	0.2	0.35	0.00	0.2	0.70	0.00	0.1	3.38	0.00	0.2	3.01	0.00	0.0	3.93	0.00	0.0
Others	1783.34	205.75	11.5	1917.13	204.59	10.7	2027.95	224.39	11.1	2223.92	215.26	9.7	2285.69	205.98	9.0	2748.08	206.88	7.5
Production/Transmission of Energy	492.81	18.27	3.7	493.12	14.96	3.0	621.30	29.42	4.7	681.46	40.70	6.0	892.06	31.09	3.5	1043.52	33.59	3.2
Shoes & Leather garments	23.74	3.05	12.8	26.63	3.00	11.3	23.07	3.47	15.0	25.39	3.81	15.0	27.17	3.77	13.9	28.36	5.31	18.7
Sugar	105.56	10.90	10.3	120.27	6.29	5.2	138.38	5.76	4.2	144.72	8.55	5.9	176.25	15.56	8.8	245.59	14.49	5.9
Textile	699.34	207.23	29.6	778.87	204.19	26.2	792.43	197.99	25.0	761.97	197.77	26.0	852.48	192.48	22.6	989.92	183.51	18.5
Total	4196.30	607.24	14.5	4505.49	585.12	13.0	4929.96	604.70	12.3	5330.14	605.44	11.4	6013.08	604.67	10.1	7029.45	592.55	8.4
Sectors	2018			2019			2020			2021			2022					
	Advances	NPLs	IR	Advances	NPLs	IR	Advances	NPLs	IR	Advances	NPLs	IR	Advances	NPLs	IR	Advances	NPLs	IR
Agribusiness	690.98	57.58	8.3	704.87	63.21	9.0	702.13	80.12	11.4	931.70	67.45	7.2	1079.38	60.49	5.6			
Automobile/Transportation	129.67	15.82	12.2	176.93	17.54	9.9	142.75	17.60	12.3	194.68	17.34	8.9	231.65	17.78	7.7			
Cement	166.96	5.06	3.0	190.56	4.15	2.2	203.77	6.19	3.0	213.27	5.48	2.6	291.48	7.06	2.4			
Chemical & Pharmaceuticals	291.29	13.03	4.5	311.43	15.15	4.9	327.34	16.71	5.1	375.42	16.55	4.4	506.74	16.28	3.2			
Electronics	117.30	16.26	13.9	120.19	20.44	17.0	110.59	22.28	20.1	150.52	24.11	16.0	171.97	24.27	14.1			
Financial	228.48	9.93	4.3	252.06	11.00	4.4	230.16	11.21	4.9	337.47	10.50	3.1	663.78	10.64	1.6			
Individuals	739.48	62.55	8.5	763.63	60.66	7.9	815.41	64.67	7.9	1071.92	63.05	5.9	1211.09	62.40	5.2			
Insurance	3.91	0.01	0.2	4.30	0.01	0.2	5.73	0.14	2.4	6.42	0.06	1.0	4.14	0.06	1.5			
Others	3297.26	232.11	7.0	3386.62	285.99	8.4	3473.40	319.44	9.2	4026.52	357.63	8.9	4502.99	411.33	9.1			
Production/Transmission of Energy	1434.62	38.79	2.7	1492.82	46.59	3.1	1393.74	58.40	4.2	1521.03	78.26	5.1	1620.99	85.44	5.3			
Shoes & Leather garments	33.72	5.67	16.8	38.63	5.95	15.4	37.39	5.68	15.2	43.64	5.48	12.5	52.89	5.92	11.2			
Sugar	234.84	40.34	17.2	220.99	50.51	22.9	238.46	56.96	23.9	251.05	58.53	23.3	292.04	58.41	20.0			
Textile	1156.28	182.61	15.8	1205.71	179.92	14.9	1342.88	169.52	12.6	1781.74	155.77	8.7	2016.21	163.94	8.1			
Total	8524.81	679.74	8.0	8868.74	761.12	8.6	9023.74	828.90	9.2	10,905.37	860.21	7.9	12,645.36	924.04	7.3			

Source: State Bank of Pakistan, IR is the infection ratio.

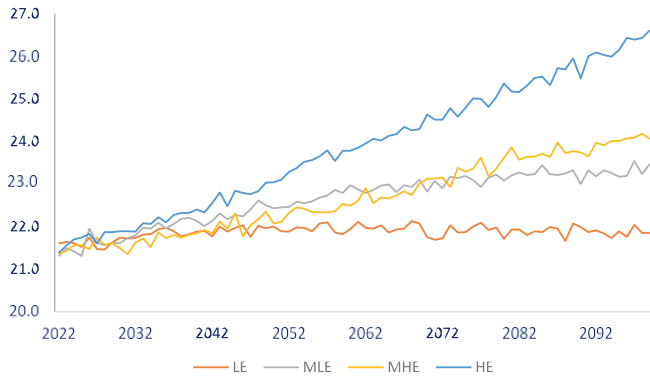


Fig. 1. Average Temperature Forecast in °C (2022—2100).

Results and discussion

The results for the macro model estimated by Eq. 1 are presented in Table 3. The statistics indicate that temperature, GDP, and credit growth are stationary. The stationarity of independent variables ensures the model's predictive capabilities' validity, reliability, and accuracy. When independent variables exhibit stationarity, their relationships with the dependent variable, the forecasted variable, remain stable and consistent over time. This stability is paramount for the model to generate accurate forecasts of future values of the dependent variable. Furthermore, stationarity allows for robust estimation of model parameters, such as the coefficients that quantify the strength of the associations between independent and dependent variables. Accurate parameter estimates are essential for producing reliable forecasts reflecting underlying data patterns.

Additionally, stationarity upholds the validity of statistical inference techniques employed to assess the significance of model parameters and the overall goodness of fit. Moreover, stationarity helps circumvent spurious relationships, which can arise when employing non-stationary independent variables. Spurious relationships occur when apparent

associations between variables stem from the time series nature of the data rather than genuine causal linkages. Stationarity safeguards against these misleading associations, ensuring the model captures true relationship between variables.

The sector-wise results of micro estimations are presented in Table 4. The estimates are based on differences in GMM (DIF GMM). We prefer DIF-GMM as it is consistent under much weaker assumptions than other estimators and produces asymptotically unbiased estimates even if unobserved heterogeneity exists. It will produce estimates with smaller standard errors, making it more likely to detect statistically significant effects. Finally, it is robust to several potential problems, such as serial correlation and heteroscedasticity (Bayangos, Cachuela, & Prado, 2021; Elmaasrawy, Tawfik, & Hussainey, 2023). The results indicate that the previous quarter's non-performing loans impact credit infections. The estimates further indicate that economic development and credit growth are negatively related to the classified loans. The impacts persist for level and up to two previous years. These observations are consistent across all sectors. The results for forecast accuracy are presented in Table 5. The statistics of RMSE, MSE, MAE, and MAPE demonstrate that our in-sample forecasts for credit infections across the period and for all sectors are precise, and this validates the robustness of our macro and micro models.

A downward trajectory of GDP growth and credit expansion increasing non-performing loans is not surprising in developing economies. This phenomenon stems from multiple factors that amplify the risk of loan defaults. Firstly, as economic growth slows, businesses encounter reduced income and profitability, hindering their ability to service existing loans. Their cash flow generation diminishes, raising the probability of non-payment of loan obligations. Secondly, during economic downturns, banks may adopt more permissive loan approval policies, extending credit to borrowers with heightened credit risk. This practice can result in a surge of NPLs as these borrowers become more susceptible to financial distress. Thirdly, some developing economies, including Pakistan, exhibit less stringent regulatory oversight of the financial sector. This regulatory laxity can empower banks to engage in riskier lending practices, elevating the likelihood of NPL formation.

Fourthly, many developing economies heavily rely on commodity exports. When commodity prices decline, the revenue of businesses and individuals associated with these industries plummets, potentially triggering loan defaults. Fifthly, currency depreciation can directly impact the ability of borrowers to repay loans, particularly if their loans are denominated in foreign currencies. A weaker currency can inflate the cost of servicing foreign-denominated loans, potentially pushing borrowers into default. Finally, a lack of diversification in the economic base of developing economies can amplify the consequences of economic downturns. Reliance on a few industries or sectors makes the economy vulnerable to domino effects, leading to widespread financial distress and soaring NPLs.

The results for credit infections under each stress scenario for years 2025, 2027, 2030, and 2035 are presented in Table 6. The findings generally demonstrate an increase in nonperforming loans across all sectors. In the low-emission scenario, we expect NPLs from the textile sector to increase to 12.5 % in 2025. A similar progression is likely in the oil and gas sector, with classified loans reaching 5.9 % (up from 3.8 % in 2022). The asset quality for other sectors also indicates a potential deterioration, but the magnitude is smaller than that of Textile and Oil and Gas. The trend is consistent in other scenarios with a significant increase in nonperforming loans if the temperature rises by 2.4 °C, 2.8 °C or 4.3 °C. The medium-term forecasts (2027 and 2030) highlight further problems related to global warming with significant degradation of credit exposures across all sectors. If the trajectory continues in the long term (2035), the nonperforming loans will likely rise to unprecedented levels, posing real threats to the banking system. This upward trend in NPLs can be attributed to the significant risks that climate change poses, particularly to the textile and oil and gas sectors, which are among the most vulnerable.

Table 3
Macroeconomic Specifications (Vector Autoregression).

	gdp		cr	
Temp	-0.27957	***	-0.50853	***
	<i>0.0002</i>		<i>0.0007</i>	
Temp ²	-0.09319	***	-0.12713	***
	<i>0.0003</i>		<i>0.0008</i>	
gdp(1)	-0.39246	***	0.713855	**
	<i>0.0001</i>		<i>0.0142</i>	
gdp(2)	-0.40009	**	0.732675	**
	<i>0.0298</i>		<i>0.0206</i>	
gdp(3)	-0.3245	**	0.505539	*
	<i>0.0269</i>		<i>0.0602</i>	
gdp(4)	-0.21303		0.393269	
	<i>0.077</i>		<i>0.0725</i>	
cr(1)	0.113004	***	-0.25374	***
	<i>0.0001</i>		<i>0.0002</i>	
cr(2)	0.135146	**	0.033097	
	<i>0.035</i>		<i>0.0816</i>	
cr(3)	0.06032		0.137579	
	<i>0.1251</i>		<i>0.098</i>	
cr(4)	0.030542		0.169378	
	<i>0.0948</i>		<i>0.0769</i>	
R-Sq	0.624		0.651	
Stationarity Tests - <i>p</i> values				
ADF	0.003333		0.003083	
Phillips-Perron	0.00114		0.000565	

p values in Italics, * is $p < 0,1$, ** is $p < 0,05$, *** is $p < 0,01$.
cr is logarithmic (ln) credit growth, gdp represents growth in gdp (ln) while (1), (2), (3) and (4) represent lags (up to four quarters).

Table 4

Panel Regressions Micro Specification (Difference GMM).

	Textile		Food, Beverages & Tobacco		Oil and Gas		Pharma		Chemicals		Automobiles		Fertilizers		Electronics		Paper & Board	
Logit NPL	0.52425	***	0.53396	***	0.45058	***	0.49405	***	0.51274	***	0.54051	***	0.56166	***	0.42311	***	0.40343	***
Temp	2.58538		2.94039		3.22266		2.85743		3.17349		4.01015		2.64267		3.06247		3.58120	
	-0.68488	***	-0.27305	***	-0.30472	**	-0.15666	***	-0.64069	***	-0.27827	**	-0.58705	**	-0.00262	**	-0.51828	**
Temp ²	-3.27578		-3.66423		-1.97281		-3.96508		-3.33532		-2.13382		-2.11941		-1.97506		-2.05521	
	-0.45286	**	-0.44418	***	-0.39451	**	-0.44142	**	-0.30520	**	-0.07317	**	-0.07065	**	-0.04200	**	-0.04862	**
gdp	-1.98638		-2.65841		-1.99814		-2.00290		-1.96223		-2.16070		-2.04601		-1.99330		-2.08515	
	-4.79907	***	-4.87786	***	-4.85406	**	-5.53667	**	-6.30840	**	-5.09272	***	-4.17908	***	-3.33041	**	-3.16904	**
gdp(1)	-4.14603		-3.85070		-2.04035		-2.01073		-1.96368		-3.26380		-3.06506		-1.96588		-2.19063	
	-2.01817	**	-2.24897	**	-2.62729	**	-2.77744	***	-2.45382	**	-2.53399	**	-3.33260	**	-3.09345	**	-3.22721	**
gdp(2)	-1.97227		-2.01075		-2.05212		-3.45928		-1.99075		-2.13367		-2.02653		-2.14927		-2.01475	
	-3.49092	**	-3.79918	**	-2.96329	**	-3.13468	**	-3.95905	***	-1.87030	**	-1.91253	**	-4.09867	**	-4.17591	**
gdp(3)	-1.98193		-2.07625		-2.10263		-2.00373		-3.26992		-2.00663		-2.02308		-2.02053		-2.09575	
	-0.85729	*	-0.85878		-0.85737		-1.25988		-1.25421		-1.29818		-1.18197		-1.11478		-1.04545	
cr	-1.80170		-1.00109		-0.65031		-0.06418		-0.25200		-0.63913		-0.06672		-0.69855		-0.58808	
	-1.57779	***	-1.58059	**	-1.23283	***	-0.76707	***	-0.76354	***	-1.01166	***	-1.25365	***	-1.41895	***	-1.33074	***
cr(1)	-3.84844		-2.02135		-4.03738		-3.48521		-2.89633		-3.03174		-4.28039		-2.68760		-3.03466	
	-1.21055	**	-1.27918	**	-0.95285	**	-0.78698	**	-0.66310	**	-0.83534	**	-0.85616	**	-1.83812	**	-1.81836	**
cr(2)	-1.99184		-2.07950		-1.98009		-2.14705		-2.15129		-2.04653		-2.03473		-1.96301		-2.16796	
	-1.79374	**	-1.85999	**	-1.21111	**	-0.88831	**	-0.93596	**	-1.29697	**	-1.18218	**	-1.72387	***	-1.67346	***
cr(3)	-1.98413		-2.00952		-1.98551		-2.12717		-1.97259		-1.98011		-2.04289		-3.05985		-2.91341	
	-0.23991		-0.25943		-0.38394	*	-0.63804		-0.48511		-0.50950		-0.44019		-0.31600		-0.31989	
AR(1) p value	-0.83875		-0.10033		-1.83209		-0.87230		-0.92892		-0.52366		-0.29420		-0.42323		-1.01133	
	0.00022		0.00056		0.00082		0.00021		0.00043		0.00095		0.00087		0.00018		0.00045	
AR(2) p value	0.15192		0.15755		0.16430		0.18409		0.15367		0.11205		0.12861		0.14550		0.14126	
	Hansen Test (<i>p</i> -value)	0.01610	0.02942		0.01271		0.02034		0.01170		0.00103		0.03232		0.01920		0.03284	

t stats in italics based on robust standard errors. *** represent significance at 1 %, ** at 5 % and * at 10 %.

Table 5

In Sample Forecast Robustness (Actual vs. Predicted NPLs).

Sectors	RMSE	MSE	MAE	MAPE
Food, Beverages & Tobacco	0.00260 %	0.00123 %	0.00100 %	0.00185 %
Oil and Gas	0.00043 %	0.00020 %	0.00016 %	0.00030 %
Pharma	0.00032 %	0.00015 %	0.00012 %	0.00022 %
Chemicals	0.00022 %	0.00010 %	0.00008 %	0.00015 %
Automobiles	0.00192 %	0.00091 %	0.00074 %	0.00137 %
Fertilizers	0.00142 %	0.00067 %	0.00055 %	0.00101 %
Electronics	0.00023 %	0.00011 %	0.00009 %	0.00017 %
Paper & Board	0.00175 %	0.00083 %	0.00067 %	0.00124 %

The textile sector is especially susceptible to climate change due to its dependence on water-intensive processes and agricultural inputs such as cotton. Rising temperatures are likely to exacerbate water scarcity, disrupting cotton production and driving up costs for water and energy. These challenges could lead to decreased profitability and operational inefficiencies, making it harder for textile companies to meet debt obligations. Furthermore, extreme weather events, including floods and droughts, can damage infrastructure and disrupt supply chains, further straining these businesses financially. As a result, the sector is expected to contribute significantly to the increase in NPLs.

To mitigate these risks, the firms must adopt climate adaptation strategies that enhance resilience. Water-efficient technologies are key for the textile industry. These include water recycling, rainwater harvesting, and drought-resistant cotton varieties. Such measures can reduce the industry's water dependence and environmental impact. Furthermore, adopting climate-smart practices can help in agriculture. Precision agriculture, improved irrigation, and climate-resilient crop varieties will support cotton production in the face of climate challenges. Close collaboration between textile manufacturers and farmers can strengthen supply chain resilience and reduce climate risks. Government policy is crucial to supporting these efforts. The government can provide incentives, such as subsidies or tax breaks, to companies investing in sustainable practices. Additionally, improving water storage and distribution infrastructure would further enhance resilience. Implementing these strategies allows the textile industry to manage climate risks better. This will help ensure long-term stability and reduce potential financial impacts on the banking sector from rising NPLs and defaults.

The oil and gas sector is also at high risk from climate change, albeit through different channels. Rising temperatures and the global shift

toward reducing greenhouse gas emissions will likely decrease demand for fossil fuels, impacting revenues and profitability. Climate policies to curb emissions will also increase regulatory costs, further squeezing profit margins. Physical impacts of climate change, such as extreme weather events, can disrupt exploration, production, and transportation activities, leading to operational challenges and potential financial losses. Consequently, companies in this sector may face heightened financial instability, contributing to more loan losses.

We present our estimates of the probability of default in Table 7, which are consistent with those of nonperforming loans. The average increase in temperature results in a significant increase in the probability of default. The impact is less intense in the low-emission scenario, and we observe high PDs as we transition to rising temperatures and higher emission scenarios. The banks' default probability increases for exposure to the textile sector, but the results are somewhat modest for loans to the oil and gas sector. As mentioned earlier, the textile industry, being highly vulnerable to climate change due to its dependence on water and agricultural inputs, tends to have less diversified financial structures. Companies in this sector have less financial flexibility and, therefore, less capacity to absorb financial shocks, and this link between increased NPLs and higher PD reflects the sector's limited resilience to climate-induced financial stress. Conversely, the oil and gas sector typically features large, well-capitalized firms with greater financial reserves, diversified revenue streams, and access to alternative financing options. The oil and gas sector often holds substantial physical assets, such as reserves, infrastructure, and equipment, which can be used as collateral. Even when NPLs rise, the value of these assets can provide a cushion for banks, mitigating the increase in the probability of default. In contrast, the textile sector's assets, such as inventory and machinery, might depreciate more quickly or hold less collateral value in the face of climate risks, leading to a stronger correlation between rising NPLs and the probability of default.

Our results have significant actionable implications for the regulators and the banking firms. Regulators and financial institutions must prioritize the creation of comprehensive climate risk frameworks that integrate both physical risks, such as those arising from extreme weather events, and transition risks associated with shifts in policy, market dynamics, and consumer behavior. These frameworks should guide banks in assessing and managing their exposure to sectors most vulnerable to climate change, ensuring they can maintain financial stability in the face of increasing risks. Within these frameworks, sector-specific risk assessments should be a cornerstone. For example, the textile sector, highly susceptible to climate disruptions, requires enhanced scrutiny

Table 6

NPL Ratio 2022 and Under Stress Scenarios.

Sectors	NPL-2022	NPL-2025				NPL-2027			
		LE	MLE	MHE	HE	LE	MLE	MHE	HE
Textile	8.388 %	12.530 %	14.454 %	15.919 %	20.096 %	14.071 %	21.105 %	22.231 %	24.654 %
Food, Beverages & Tobacco	3.596 %	4.771 %	5.019 %	7.752 %	12.184 %	5.397 %	9.770 %	10.622 %	16.492 %
Oil and Gas	3.870 %	5.907 %	7.270 %	11.381 %	16.096 %	6.793 %	9.447 %	15.619 %	20.761 %
Pharma	3.875 %	3.199 %	3.662 %	5.025 %	4.936 %	3.527 %	6.663 %	7.397 %	7.502 %
Chemicals	3.361 %	3.189 %	3.712 %	4.607 %	6.520 %	3.573 %	4.422 %	5.060 %	9.598 %
Automobiles	4.130 %	5.383 %	6.461 %	7.750 %	8.072 %	6.031 %	10.342 %	10.412 %	11.203 %
Fertilizers	4.241 %	5.634 %	6.396 %	7.637 %	8.896 %	6.767 %	12.667 %	14.873 %	16.976 %
Electronics	8.013 %	6.923 %	8.515 %	11.155 %	15.728 %	7.706 %	14.485 %	15.526 %	18.148 %
Paper & Board	6.590 %	5.800 %	8.191 %	12.387 %	16.369 %	6.613 %	9.579 %	23.443 %	24.979 %
		NPL-2030				NPL-2035			
		LE	MLE	MHE	HE	LE	MLE	MHE	HE
Textile		21.072 %	23.934 %	25.254 %	32.523 %	26.439 %	31.173 %	31.626 %	42.328 %
Food, Beverages & Tobacco		8.174 %	10.377 %	14.778 %	19.673 %	9.240 %	16.817 %	18.834 %	30.147 %
Oil and Gas		11.813 %	12.173 %	21.872 %	22.689 %	15.137 %	25.948 %	28.404 %	33.221 %
Pharma		3.948 %	9.115 %	8.830 %	10.134 %	5.040 %	10.113 %	11.328 %	12.171 %
Chemicals		6.023 %	4.481 %	6.075 %	11.331 %	7.748 %	8.709 %	8.991 %	16.668 %
Automobiles		9.272 %	10.715 %	12.952 %	15.485 %	12.559 %	16.354 %	17.827 %	19.284 %
Fertilizers		13.402 %	19.913 %	19.732 %	20.504 %	17.717 %	23.095 %	22.664 %	32.142 %
Electronics		12.478 %	16.447 %	18.698 %	20.113 %	15.694 %	22.125 %	21.593 %	33.548 %
Paper & Board		10.703 %	13.773 %	26.743 %	29.327 %	13.371 %	30.132 %	31.249 %	35.296 %

Table 7
Sectoral PDs 2021 and Under Stress Scenarios (NPLs Based).

Sectors	PDs-2022	PDs-2025				PDs-2027			
		LE	MLE	MHE	HE	LE	MLE	MHE	HE
Textile	3.376 %	5.199 %	6.132 %	7.813 %	11.173 %	5.937 %	7.862 %	9.744 %	12.334 %
Food, Beverages & Tobacco	1.140 %	1.859 %	3.307 %	3.753 %	4.410 %	2.619 %	4.206 %	5.846 %	6.614 %
Oil and Gas	0.141 %	0.244 %	0.363 %	0.689 %	1.335 %	1.178 %	2.040 %	3.317 %	6.387 %
Pharma	0.228 %	0.253 %	0.313 %	0.317 %	0.364 %	0.458 %	0.487 %	0.554 %	0.555 %
Chemicals	0.195 %	0.246 %	0.336 %	0.431 %	0.714 %	0.381 %	0.446 %	0.694 %	0.960 %
Automobiles	0.315 %	0.426 %	0.820 %	1.452 %	2.585 %	0.580 %	1.492 %	2.330 %	2.749 %
Fertilizers	1.064 %	1.112 %	1.927 %	1.969 %	3.571 %	1.816 %	2.329 %	2.647 %	6.754 %
Electronics	0.269 %	0.434 %	0.631 %	0.692 %	1.109 %	0.700 %	0.754 %	1.045 %	2.212 %
Paper & Board	0.118 %	0.915 %	0.994 %	1.652 %	2.403 %	1.739 %	1.934 %	2.953 %	2.948 %
PDs-2030									
		LE	MLE	MHE	HE	LE	MLE	MHE	HE
Textile		6.134 %	9.473 %	12.516 %	15.301 %	7.514 %	11.460 %	13.853 %	16.846 %
Food, Beverages & Tobacco		4.108 %	4.400 %	10.914 %	13.937 %	5.858 %	7.489 %	12.334 %	16.535 %
Oil and Gas		1.357 %	2.792 %	5.857 %	7.843 %	9.345 %	12.134 %	14.350 %	20.921 %
Pharma		0.809 %	1.278 %	2.301 %	2.464 %	4.333 %	6.799 %	9.136 %	9.198 %
Chemicals		0.574 %	0.830 %	0.906 %	1.736 %	0.968 %	1.123 %	1.794 %	2.686 %
Automobiles		0.822 %	2.556 %	4.480 %	6.014 %	0.973 %	3.579 %	4.612 %	9.205 %
Fertilizers		3.348 %	3.529 %	4.793 %	7.183 %	4.180 %	6.821 %	7.334 %	8.655 %
Electronics		1.317 %	0.934 %	1.239 %	3.553 %	2.550 %	3.596 %	4.776 %	5.482 %
Paper & Board		2.755 %	3.245 %	4.767 %	4.795 %	3.334 %	3.777 %	5.970 %	8.684 %

and tailored risk management strategies. Policymakers should consider dynamic adjustments to capital requirements based on banks' climate risk exposure. By aligning capital buffers with the level of climate risk in specific sectors, regulators can help banks maintain resilience against potential financial shocks brought on by climate change. Banks should be encouraged to lend to firms that adopt climate-resilient practices through incentives and regulatory support. This reduces the financial risks of climate change and aligns banking practices with broader environmental sustainability goals.

Conclusion

This study examines the impact of climate change on Pakistan's banking sector, focusing on asset quality and the probability of default under different climate scenarios. Our findings indicate that rising temperatures will intensify financial vulnerabilities, particularly in textiles and oil and gas. These sectors are critical to Pakistan's economy and highly susceptible to climate-related disruptions, which could increase non-performing loans and varying default probabilities.

Banks must incorporate climate risk assessments into their financial management frameworks, given these risks. Traditional risk management models, which often focus on short-term risks, are inadequate for addressing the long-term impact of climate change. Banks need to adopt comprehensive climate risk frameworks that are more aligned with each sector's unique vulnerabilities. Scenario analysis and stress testing should become standard practices to help banks better understand the potential financial impacts of climate risks and to identify areas where intervention is needed.

Regulatory authorities are also important in improving the financial sector's resilience. Policymakers should introduce dynamic capital adequacy requirements that reflect climate-related risks, ensuring banks are better equipped to absorb potential financial shocks. In addition, regulators should encourage lending to companies that invest in climate-resilient technologies and sustainable practices. Offering favorable financial terms for such firms would incentivize banks to align their portfolios with the global transition toward sustainability, helping both the economy and the environment.

The broader implications of this study point to the urgent need for climate change mitigation and adaptation strategies in emerging markets. Despite their relatively small historical contributions to global emissions, these economies are particularly vulnerable to climate risks. They must take immediate and proactive measures to protect their financial systems and economic stability. Future research should expand

the scope by examining the impact of climate change on other sectors, such as agriculture, infrastructure, and energy, all of which are crucial to the economic fabric of developing countries. Longitudinal studies would also provide valuable insights into the long-term financial effects of climate change. Furthermore, future work should consider incorporating more granular data on climate risk exposure and refine risk models, potentially utilizing advanced techniques like machine learning to predict climate-related financial instability more accurately.

In conclusion, the banking sector in Pakistan faces significant climate-related risks. Still, these challenges also present an opportunity for the sector to lead in integrating climate risk into its operations. Both banks and regulators must act decisively to ensure financial resilience in the face of these emerging threats. Since climate change disproportionately impacts emerging markets, these economies must prioritize climate adaptation strategies to safeguard their financial systems and economic stability. Global cooperation will be essential in this effort. Developed nations must provide the necessary support, including technology transfer, financial assistance, and capacity-building, to help emerging markets effectively address climate change risks and build a more resilient future.

Data availability

Data will be made available on request.

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