

Integrating Climate Risk into Basel III: Evidence from Indian Commercial Banks and a Proposed Climate-Adjusted Basel Risk Framework (CABRF)



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Abstract

Climate change is increasingly recognised as a financial stability concern because physical hazards and the transition to a low-carbon economy can weaken borrowers, reduce collateral values, increase credit losses and alter banks' capital requirements. This study examines whether bank-specific climate exposure is associated with capital adequacy in Indian commercial banks and develops a Climate-Adjusted Basel Risk Framework (CABRF) that translates observed exposure into a prudential capital overlay. The study uses a hand-collected panel of ten major Indian public- and private-sector commercial banks for FY2015–FY2024. The analysis combines bank-level Basel III indicators with sectoral lending, climate-governance and green-finance disclosure measures and national physical-hazard indicators. A Climate Risk Exposure Index (CREI) is constructed as the interaction of a Climate Hazard Index (CHI) and a Bank Exposure Score (BES). Fixed-effects, random-effects and pooled estimations are complemented by robustness specifications. The preferred fixed-effects model reports a negative and statistically significant coefficient for CREI (−2.42), while the decomposition indicates that BES, rather than the year-common CHI, is the principal driver of the association. The results also indicate that the relationship is more evident for the total capital ratio than for CET1. Based on these findings, CABRF is proposed as a supervisory overlay under Pillar II rather than as a replacement for Basel III Pillar I requirements. The framework adjusts risk-weighted assets according to observed climate exposure and produces a Climate-Adjusted Capital Adequacy Ratio. The paper contributes to the emerging literature on climate-related prudential regulation by linking bank-level empirical evidence to an operational capital framework for an emerging-market banking system.

Keywords: climate risk; banking stability; Basel III; capital adequacy; climate finance; prudential regulation; Indian commercial banks; climate-adjusted risk-weighted assets; CABRF

1. Introduction

Climate change has become a real financial risk for the environment and for development. Physical risks, such as floods, droughts, cyclones and heat waves, can affect assets, disrupt production and distribution, reduce income and affect the value of collateral. Transition risks – the risk of policy changes, technological innovation, changes in consumers' behavior and in the relative profitability of activities, including those that are carbon-intensive and others – pose risks for banks through potential credit losses and impacts on the value of assets as well as through potential operational risks and liquidity risks ((Battiston et al., 2021), (Network for Greening the Financial System, 2021), ([BCBS], 2022).

For commercial banks, the prudential implications are particularly important because banks transform savings into credit and maintain large exposures to households, firms and infrastructure. Climate-sensitive sectors—including agriculture, energy, transportation, infrastructure, manufacturing and real estate—can transmit physical and transition shocks into borrowers' debt-servicing capacity. An adverse climate event can increase probability of default and loss given default, while transition

policies can reduce the value of carbon-intensive assets or create stranded assets (Chodnicka-Jaworska & Ferrari, 2026). Consequently, climate risk can ultimately affect the quality and riskiness of banks' assets and therefore their capital adequacy (Dietz et al., 2016); (Battiston et al., 2017, 2021)).

The issue is not whether the banking sector is exposed to risks from climate change, but whether current capital requirements address those risks sufficiently. Basel III strengthened bank resilience through higher-quality capital, capital buffers, leverage constraints and liquidity standards. However, climate-related financial risks were not a stated objective of the original Basel III reforms, which were primarily designed to strengthen banks' resilience to conventional financial and systemic risks. The Basel Committee has subsequently recognized climate-related financial risks as relevant to banks' safety and soundness and has issued principles covering governance, risk management and supervision. It has also clarified that material climate-related financial risks can, where relevant, be captured within the existing Basel Framework, while recognising continuing challenges in measurement

and implementation (Basel Committee on Banking Supervision, 2021) ([BCBS], 2022). Importantly, the Basel Committee's work also emphasises that existing Basel standards can already capture some climate-related risks, while supervisory responses and measurement practices continue to evolve ([BCBS], 2022). A related strand of research documents substantial variability in banks' risk-weighted asset calculations across jurisdictions even for similar underlying exposures, which is directly relevant to any climate adjustment applied through the RWA denominator (Basel Committee on Banking Supervision, 2013); (Le Leslé & Avramova, 2012).

India provides an important setting in which to examine this issue. The banking system is central to financial intermediation, while banks maintain significant risk to sectors that are sensitive to both physical hazards and the low-carbon transition. The Reserve Bank of India (RBI) has progressively developed a climate-risk agenda including climate vulnerability assessment, scenario analysis, stress testing, disclosure and data infrastructure. Its 2022 pilot Climate Vulnerability Assessment and Stress Testing (VAST) exercise found an increase in banks' credit-loss potential under physical and transition-risk scenarios, while drawing attention to the importance of granular climate-risk data. Importantly, the exercise was exploratory and was not designed to assess capital adequacy or prescribe minimum capital requirements (RBI, 2024a). The RBI has also moved toward standardised climate-related financial-risk disclosures. Its 2024 draft disclosure framework proposed qualitative and quantitative disclosures covering governance, strategy, risk management, and metrics and targets, reflecting the need for more consistent climate-risk information for financial assessment and market discipline (RBI, 2024a)(RBI, 2024b)

Despite these developments, a gap remains between the measurement of climate exposure and its translation into prudential capital assessment. Existing research has examined climate-related financial risk through financial stability, asset valuation, credit risk, stress testing and broader prudential-policy channels ((Battiston et al., 2017) (Campiglio et al., 2018; Monasterolo, n.d.)). However, relatively fewer studies directly connect a bank-level climate exposure measure to Basel III capital adequacy and then use that evidence to construct a transparent supervisory capital overlay. This study addresses that gap by combining panel evidence from major Indian commercial banks with a Climate-Adjusted Basel Risk Framework (CABRF).

The study makes three principal contributions. First, it provides bank-level empirical evidence on the association between climate exposure and capital

adequacy in an emerging-market banking system. Second, it separates combined physical-hazard conditions from bank-specific exposure, allowing the analysis to identify whether capital vulnerability is driven more by the national climate environment or by the composition and governance of individual bank portfolios. Third, it translates the empirical relationship into a prudential cover that adjusts risk-weighted assets and capital adequacy without requiring a redesign of the existing Basel III architecture.

The rest of the paper is organized as follows. First, the literature review and hypothesis development follow. Then there is the section on data, variables, and methodology of estimation. Next comes the presentation of the results and robustness checks. This paper develops CABRF and demonstrates its prudential application. This paper also discusses implications, limitations and future research.

Literature Review and Research Hypotheses

● Climate Risk and Banking Stability

Climate-related financial risk is commonly divided into physical and transition risk. Physical risk reflects the financial consequences of acute events and chronic climatic changes, while transition risk reflects changes associated with moving toward a lower-carbon economy. Both channels can influence banks through existing financial-risk categories. Physical events may damage collateral, disrupt borrowers' operations and reduce income, while transition policies and technologies can reduce the value of carbon-intensive assets and weaken borrowers' capacity to service debt ((Dietz et al., 2016; Monasterolo, n.d.)).(Basel Committee on Banking Supervision, 2021)

(Battiston et al., 2017) show that climate stress can propagate through financial networks because banks may be exposed to firms and sectors whose valuations are sensitive to climate policy. (Campiglio et al., 2018) similarly argues that financial institutions play a critical role in financing the transition and that monetary and banking policy can influence the allocation of capital. (Lamperti et al., 2021) demonstrate that alternative green-finance policies can influence climate-related financial stability through interactions between the financial system and the real economy. Empirical work on catastrophe risk and bank lending finds that flood exposure is negatively associated with lending to affected firms, providing micro-level evidence that physical climate risk transmits into credit allocation (Faiella & Natoli, 2018) Cross-country evidence from the Eurosystem's climate stress test similarly shows that transition and physical risk scenarios produce materially higher risk estimates than orderly-transition baselines, reinforcing the case for capital-

relevant climate metrics (European Central Bank, 2023). Empirical work on catastrophe risk and bank lending finds that flood exposure is negatively associated with lending to affected firms, providing micro-level evidence that physical climate risk transmits into credit allocation (Faiella & Natoli, 2018). Cross-country evidence from the Eurosystem's climate stress test similarly shows that transition and physical risk scenarios produce materially higher risk estimates than orderly-transition baselines, reinforcing the case for capital-relevant climate metrics (European Central Bank, 2023).

Climate risk therefore differs from a traditional risk category. It is better understood as a risk driver which can modify the probability and intensity of credit, market, operational and liquidity losses (Battiston et al., 2017). This interpretation is consistent with the Basel Committee's approach, which seeks to include substantial climate-related financial risks within existing risk-management and prudential frameworks rather than automatically treating climate risk as a separate regulatory risk category (Basel Committee on Banking Supervision, 2021) ([BCBS], 2022)

● Climate Risk and Prudential Regulation

The financial regulation has considered approaches such as preferential capital treatment for sustainable investments and higher capital requirements for carbon-intensive exposures. These approaches are commonly discussed as the Green Supporting Factor and Brown Penalizing Factor, respectively. A key risk management concern is whether climate-sensitive capital adjustments reflect underlying financial risk rather than functioning primarily as an industrial-policy instrument (Campiglio et al., 2018; D'Orazio & Popoyan, 2019). This distinction is important because a climate-sensitive capital framework should penalise exposures according to their economic exposure to climate risk, not simply according to whether an activity is labelled green or brown. This concern is reinforced by evidence that ESG disclosure quality among banks is uneven and not yet consistently linked to underlying financial performance, underscoring the need for climate-risk measures grounded in exposure rather than disclosure alone (Adamska & Dąbrowski, 2021).

Climate stress testing provides another approach. Stress tests evaluate how banks' balance sheets may respond to alternative physical and transition scenarios. NGFS scenarios provide a common basis for forward-looking climate-risk assessment, while central banks increasingly use scenario analysis to understand the macro-financial transmission of climate shocks (Network for Greening the Financial System, 2021) (Network for Greening the Financial System, 2023). Nevertheless, climate scenario

analysis primarily provides a forward-looking assessment of risk and does not, by itself, establish a permanent adjustment to regulatory capital. This distinction creates an opportunity to examine whether empirically observed climate exposure can inform a calibrated supervisory capital overlay (Network for Greening the Financial System, 2023). The resulting gap between risk assessment and capital allocation creates an opportunity for an empirically calibrated supervisory overlay. ([BCBS], 2022)

The Basel Committee's recent guidance is especially relevant. The 2022 principles establish expectations for banks and supervisors covering governance, internal controls, risk assessment, management and reporting of climate-related financial risks (Madaus, Sarra, & Mevorach, 2024). The Committee has also clarified that existing Basel Framework standards can capture climate-related financial risks in relevant cases and that the supervisory review process is an important channel for addressing material climate exposures ([BCBS], 2022). This supports a cautious approach in which climate-sensitive capital adjustments are first developed as institution-specific supervisory measures rather than assumed to require immediate changes to minimum Pillar I risk weights. ([BCBS], 2022)

● Indian Banking Context

India provides an important setting for examining climate-related financial risk because of its exposure to physical climate hazards and the central role of banks in financing households, firms and infrastructure. Indian banks also maintain material exposures to climate-sensitive sectors, creating potential channels through which physical and transition risks can affect credit quality. The RBI has recognised climate change as an emerging risk for regulated entities and financial stability. The RBI's 2022 pilot Climate Vulnerability Assessment and Stress Testing (VAST) exercise (Das & Asapur, 2024) assessed the effects of physical and transition risks on selected banks and found a substantial increase in credit-loss potential. The exercise also highlighted the challenges associated with limited granular and reliable climate-risk data; importantly, it was exploratory and was not designed to assess capital adequacy or prescribe minimum capital levels (RBI, 2024a). This is consistent with the broader Indian banking literature, which finds that non-performing assets are jointly determined by bank-specific factors such as capital adequacy and operating efficiency and by macro-financial conditions including GDP growth and policy rates (Rajaraman & Vasishta, 2002).

The RBI's climate-risk agenda also reflects a broader shift from qualitative awareness toward structured information. The 2024 draft disclosure framework proposed consistent reporting around governance,

strategy, risk management, and metrics and targets (Smits, René, 2024). Such standardisation has the potential to improve the information environment for future climate-risk measurement and supervisory assessment (RBI, 2024b).

● Research Gap and Hypotheses

Three gaps motivate the present study. First, much of the existing evidence examines climate risk through broad financial performance or disclosure outcomes rather than directly through regulatory capital. Second, physical climate conditions are often analysed at the macro level, while bank-specific portfolio exposure and governance can differ substantially across institutions. Third, conceptual proposals for climate-sensitive capital regulation are not always empirically linked to bank-level capital outcomes. This study addresses these gaps by constructing CREI from a national physical-hazard component and a bank-specific exposure component, estimating its relationship with CAR, and using the estimated relationship to motivate CABRF.

The empirical hypotheses are therefore:

- **H1:** Climate risk exposure is negatively associated with the capital adequacy of Indian

- commercial banks.
- **H2:** Bank-specific climate exposure has a stronger association with capital adequacy than aggregate physical climate hazards.
- **H3:** A climate-sensitive adjustment to risk-weighted assets provides a more risk-sensitive prudential assessment than conventional Basel III capital adequacy alone.

Data and Methodology

● Sample and Data Sources

The empirical analysis uses a hand-collected balanced panel framework covering ten major Indian commercial banks, comprising five public-sector banks and five private-sector banks, over FY2014–15 to FY2023–24. The selected banks are Axis Bank, Bank of Baroda, Bank of India, Canara Bank, Central Bank of India, HDFC Bank, ICICI Bank, Kotak Mahindra Bank, State Bank of India and Yes Bank. The sample was selected to provide representation from both major ownership groups within the Indian commercial banking system and to enable cross-bank comparison of climate exposure and capital adequacy.

No.	Bank	Ownership
1	Axis Bank	Private Sector
2	Bank of Baroda	Public Sector
3	Bank of India	Public Sector
4	Canara Bank	Public Sector
5	Central Bank of India	Public Sector
6	HDFC Bank	Private Sector
7	ICICI Bank	Private Sector
8	Kotak Mahindra Bank	Private Sector
9	State Bank of India	Public Sector
10	Yes Bank	Private Sector
Total	10 banks	5 Public + 5 Private

Source: Authors' compilation based on bank annual reports, Basel III Pillar 3 disclosures and Reserve Bank of India sources.

The maximum panel consists of 100 bank-year observations (10 banks × 10 financial years). However, differences in the availability of individual variables result in an effective estimation sample of

73 observations for the principal regression models. Bank-level financial and prudential data are obtained from annual reports, Basel III Pillar 3 disclosures and Reserve Bank of India sources. These include capital adequacy ratio (CAR), Common Equity Tier 1 (CET1), risk-weighted assets (RWA), gross and net non-performing assets, profitability, net interest margin and bank size. Climate and green-finance indicators

are hand-collected from sustainability reports, business-responsibility disclosures and related bank reports. Physical-hazard indicators include annual rainfall deviation, flood events, cyclone occurrences and heatwave days. Macroeconomic controls include GDP growth, inflation and the RBI policy/repo rate.

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Variable	Role	Measurement / source
CAR	Dependent	Total capital / risk-weighted assets; annual bank disclosures
CET1	Robustness DV	Common Equity Tier 1 ratio
CREI	Main independent	$CHI \times BES$
CHI	Climate hazard	Normalised rainfall deviation, floods, cyclones, heatwaves
BES	Bank exposure	Sector exposure, renewable exposure, governance/disclosure indicators
GNPA	Control	Gross non-performing assets ratio
ROA	Control	Return on assets
$\ln(\text{Assets})$	Control	Natural log of total assets
Public	Control	Public-sector bank dummy
GDP growth	Macro control	Annual GDP growth
Inflation	Macro control	CPI inflation
Repo rate	Macro control	RBI policy rate

● Construction of the Climate Risk Exposure Index

The central measurement challenge is that there is no universally accepted bank-level climate-risk indicator for the historical Indian sample. The study therefore constructs a composite Climate Risk Exposure Index (CREI) designed to distinguish the climate environment from bank-specific exposure.

The Climate Hazard Index (CHI) aggregates four physical-hazard indicators: rainfall deviation, floods, cyclones and heatwave days. Each series is normalised to the unit interval and combined into a composite score. Because the underlying hazard variables are measured at the national level, CHI is

common to all banks in a given year.

The Bank Exposure Score (BES) captures bank-specific transition and climate exposure. It combines lending concentration in brown or carbon-intensive sectors, renewable-energy exposure, and qualitative measures of climate governance and green-finance disclosure. These components are normalised and aggregated to produce a 0–1 score. The resulting measure should be interpreted as a portfolio-level exposure proxy rather than a borrower-level climate-risk probability.

The headline CREI is defined as:

$$CREI_{it} = CHI_t \times BES_{it}$$

The interaction reflects the proposition that a bank's climate vulnerability is greatest when a material climate hazard coincides with substantial institution-specific exposure. This structure also avoids treating a national weather event as equally risky for every bank regardless of portfolio.

● Empirical Model

The model estimates the association between climate exposure and bank capital adequacy using a bank specific variable model:

$$CAR_{it} = \alpha + \beta_1 CREI_{it} + \beta_2 GNPA_{it} + \beta_3 ROA_{it} + \beta_4 \ln(Assets_{it}) + \beta_5 Public_i + \beta_6 M_t + \mu_i + \varepsilon_{it}$$

where CAR is the total capital adequacy ratio; CREI is the climate exposure index; GNPA, ROA and bank size represent bank fundamentals; Public identifies ownership; M denotes macro-financial controls; μ_i captures time-invariant bank effects; and ε_{it} is the idiosyncratic error term. Because the ownership proxy is time-invariant, it is absorbed in the fixed-effects model. A combined OLS framework and random-effects model are estimated as benchmarks. A two-way fixed-effects specification is used as a stress test; year-common macro controls and CHI are then absorbed by year effects. Choice of methodology is informed by the Hausman test. Standard errors in the fixed-effects specifications are clustered by bank. The analysis also considers heteroskedasticity, multicollinearity and alternative specifications. The final empirical strategy is deliberately narrower than the earlier research design in order to match the

estimations actually reported in the study and to avoid presenting unexecuted methods as evidence. The fixed- versus random-effects choice and the use of cluster-robust standard errors follow standard panel-data econometric practice for firm- and bank-level panels (Wooldridge, 2010) (Baltagi, 2021).

● Robustness Strategy

Seven robustness exercises are reported. The baseline is bank fixed effects with clustered standard errors. Additional tests use heteroskedasticity-robust standard errors, substitute BES for CREI, enter CHI and BES separately, replace ROA with ROE, use a parsimonious specification, and replace CAR with CET1. This design is particularly useful because it tests whether the headline climate coefficient is driven by the construction of CREI, by the choice of profitability control, or by the distinction between total capital and core equity.

Empirical Results

● Descriptive Statistics

The sample has a mean CAR of 15.62%, with a standard deviation of 2.82 percentage points and a range of 9.61% to 23.40%. Mean CREI is 0.333, while BES and CHI average 0.609 and 0.551 respectively. Mean GNPA is 6.40%, reflecting the asset-quality stress experienced by Indian banks during part of the sample period, while mean ROA is 0.92%. GDP growth averages 6.08%, inflation 5.09% and the repo rate 5.82%.

Variable	N	Mean	SD	Min	Max
CAR (%)	93	15.62	2.82	9.61	23.40
CREI	100	0.333	0.152	0.058	0.761
BES	100	0.609	0.228	0.144	1.000
CHI	100	0.551	0.158	0.327	0.895
GNPA (%)	90	6.40	5.05	0.87	21.48
ROA (%)	79	0.92	0.93	-1.70	2.61
ROE (%)	96	7.16	10.96	-30.00	20.36
ln(Assets)	100	8.97	0.86	6.97	11.53
GDP growth (%)	100	6.08	4.23	-5.80	9.20
Inflation (%)	100	5.09	1.02	3.40	6.70
Repo rate (%)	100	5.82	1.17	4.00	7.50

● Correlation and Multicollinearity

CREI is negatively correlated with CAR ($r = -0.47$), while BES has a stronger negative correlation with CAR ($r = -0.64$). ROA and GNPA are strongly negatively correlated ($r = -0.86$), supporting the

decision to retain one profitability measure in the baseline specification. Governance and disclosure components are also strongly correlated with BES, with absolute correlations approaching 0.93. The primary specification therefore uses the index CREI rather than entering all highly correlated climate

components simultaneously.

VIF statistics for the chosen specification remain within standard benchmarks: CREI 1.59, GNPA 4.32, ROA 6.44, $\ln(\text{Assets})$ 1.52, Public 3.51, with macro controls below 1.8. These results do not indicate severe variable intercorrelation in the final specification, although the relatively high VIF for ROA requires careful reading.

● Baseline Regression Results

The central result is a negative relationship between

climate exposure and capital adequacy. The CREI coefficient is -3.452 in pooled OLS ($p = 0.014$), -2.416 in fixed effects ($p = 0.038$), -2.963 in random effects ($p = 0.028$), and -5.092 in the two-way fixed-effects specification ($p = 0.041$). The consistency of the sign across estimators supports H1. The preferred fixed-effects coefficient implies that moving from the lowest observed CREI value of approximately 0.06 to the highest value of approximately 0.76 is associated with a reduction in CAR of roughly 1.7 percentage points, holding the included controls constant.

Variable	Pooled OLS	Fixed Effects	Random Effects	Two-way FE
CREI	-3.452^{**}	-2.416^{**}	-2.963^{**}	-5.092^{**}
GNPA	0.096	-0.011	0.049	-0.043
ROA	1.414^{***}	-0.021	0.730	-0.161
$\ln(\text{Assets})$	-0.006	0.685	0.214	-0.155
Public	-2.418^{***}	—	-3.251^{***}	—
GDP growth	0.046	0.072^{**}	0.061	—
Inflation	0.483^{**}	0.643^{***}	0.583^{***}	—
Repo rate	-0.895^{***}	-0.639^{***}	-0.790^{***}	—
Observations	73	73	73	73
Within / Overall R^2	0.428 / 0.802	0.556 / 0.229	0.515 / 0.788	0.067 / 0.190

Notes: $** p < 0.05$; $*** p < 0.01$. Bank-clustered standard errors are used for the fixed-effects models. The Public dummy is absorbed by bank fixed effects. Year-common macro variables are absorbed in the two-way fixed-effects specification.

● Model Selection and Diagnostics

The Hausman test rejects the random-effects orthogonality assumption ($\chi^2(7) = 41.38$, p approximately 6.8×10^{-7}), supporting fixed effects as

the preferred estimator. The Breusch–Pagan heteroskedasticity test is insignificant ($LM = 7.71$, $p = 0.462$), although clustered standard errors are retained as a conservative treatment of within-bank dependence. The random-effects LM test is borderline ($LM = 3.30$, $p = 0.069$), but the Hausman result provides a stronger basis for the final estimator choice.

● Robustness Results

Specification	Climate variable	Coefficient	SE	p-value	N
R1: baseline FE	CREI	-2.416	1.138	0.038	73
R2: robust SE	CREI	-2.416	1.356	0.080	73
R3: alternative exposure	BES	-3.933	0.968	0.0002	73
R4: decomposition	CHI	-0.007	0.604	0.991	73
R4: decomposition	BES	-3.934	1.003	0.0002	73
R5: ROE control	CREI	-2.635	1.174	0.028	83
R6: parsimonious	CREI	-2.840	1.310	0.034	85
R7: DV = CET1	CREI	-0.846	1.252	0.502	66

The robustness results strengthen rather than weaken the central interpretation. The CREI coefficient remains negative when alternative standard errors, profitability controls and simple specifications are used. Most importantly, the

analysis shows that BES is strongly associated with CAR whereas CHI is insignificant in both size and statistics. This supports H2: the bank-specific structure and governance of exposure appear more relevant for observed capital adequacy than the

national environment exposed to environmental event in isolation.

The CET1 specification produces a negative but statistically insignificant coefficient (-0.846 , $p = 0.502$). The evidence therefore does not justify claiming that climate exposure reduces every component of regulatory capital. Rather, within this sample, the association is more evident in the total capital ratio. This distinction is important for regulatory interpretation and supports a cautious Pillar II adjustment rather than an immediate claim that climate risk requires a new minimum CET1 requirement.

Climate-Adjusted Basel Risk Framework (CABRF)

● Rationale and Regulatory Positioning

The statistical data justifies a framework that links measured climate exposure to risk-weighted assets without replacing the Basel III framework. CABRF is therefore designed as a regulatory adjustment. This approach is consistent with the Basel Committee's recognition that climate-related financial risks can be addressed through existing regulatory processes and risk-management expectations, while acknowledging the evolving state of climate-risk measurement ([BCBS], 2022).

The framework follows five steps: (1) measure physical and bank-specific exposure; (2) combine the two components into CREI; (3) translate CREI into a climate adjustment to RWA; (4) calculate the resulting climate-adjusted capital ratio; and (5) use the result as an input into regulatory review, stress testing and capital planning.

Conceptually:

Climate hazards → CHI → Bank exposure/BES → CREI → Climate-adjusted RWA → Climate-adjusted CAR

● Mathematical Structure

Conventional Basel capital adequacy is represented as:

$$CAR_{it} = TC_{it} / RWA_{it}$$

where TC denotes total regulatory capital and RWA denotes risk-weighted assets. CABRF assumes that

climate risk primarily changes the effective riskiness of exposures and therefore operates through the denominator. Climate adjusted risk-weighted assets are defined as:

$$CRWA_{it} = RWA_{it} \times (1 + \lambda CREI_{it})$$

where λ is the climate sensitivity parameter. The resulting climate-adjusted capital adequacy ratio is:

$$CCAR_{it} = TC_{it} / CRWA_{it} = CAR_{it} / (1 + \lambda CREI_{it})$$

This reduced-form expression is intentionally transparent. Rather than auditing or rebuilding the bank's internal Basel capital models, regulators can simply adjust reported RWAs. This is done by applying a climate adjustment driven by an exposure score and a tuned sensitivity metric.

● Supporting Credit-Risk Components

CABRF also suggests the use of extensions which are consistent conceptually with Basel internal-risk methods. Climate-adjusted probability of default can be formulated in terms of $CPD = PD \times (1 + \theta CREI)$, while climate-adjusted loss given default can be written in terms of $CLGD = LGD \times (1 + \phi CREI)$. These variables have not been empirically calibrated within this study since the individual climate information for borrowers is unavailable. They must, therefore, be considered as extensions of future regulatory data sets.

The climate-adjusted risk weight can be expressed as $CRW = RW \times (1 + \lambda CREI)$. The corresponding capital adjustment is $CCB = CRWA - RWA = \lambda CREI \times RWA$. The advantage of this structure is that it preserves the existing Basel risk-weighting framework while making the climate exposure transparent.

● Calibration and Scenario Illustration

The alignment of the climate sensitivity parameter is done with regard to the statistical data provided by the fixed-effects model and the subsequent application of this parameter for scenario analysis. The alignment must be understood as a statistical demonstration and not a regulatory standard. Since the coefficient obtained in the CAR regression is a different object from the λ parameter in the RWA adjustment, the alignment must be considered as a regulatory calibration exercise.

Scenario	λ	Illustrative effect on RWA for CREI = 0.50	CCAR relative to CAR
Low sensitivity	0.10	$RWA \times 1.05$	$CAR / 1.05$
Baseline sensitivity	0.15	$RWA \times 1.075$	$CAR / 1.075$
High sensitivity	0.20	$RWA \times 1.10$	$CAR / 1.10$

In the baseline example, λ has a value of 0.15, which aligns with what the paper reports. For a bank with $CREI = 0.50$, the increase in RWAs through adjustment is 7.5%. The example is not meant to suggest a blanket 7.5% increase in the capital requirement for all banks, but rather to show the

process of adjustment.

● Why a Pillar II Overlay is Preferable

Three key factors justify why a regulatory rather than universal Pillar I approach to implementing Pillar I is appropriate. The first reason is that there are major

variations in climate exposure among banks. The second reason is that historical climate data are incomplete and are based on indicators. The third reason is that CET1 is not statistically significant. A differentiated Pillar II add-on would enable regulators to consider material institution-specific exposure without jumping to conclusions about climate risk and universal change to minimum capital requirements.

This approach is in line with the current regulatory developments internationally as well. The Basel Committee's principles stress the regulator's expectations and risk management, whereas the climate-risk FAQ clarifies that climate risks can be accounted for in the existing Basel requirements when applicable ([BCBS], 2022). This means that CABRF could be considered as a potential data-driven procedure for enhancing regulatory review, not as an attempt to replace Basel III ([BCBS], 2022).

Discussion, Policy Implications and Limitations

● Interpretation of Findings

The core empirical result is that the greater climate risk vulnerability is positively related to reduced capital adequacy even after the control for bank characteristics and macroeconomic variables. This result fits well with other studies that prove that climate risk can be transmitted via credit quality and asset valuation (Battiston et al., 2021; Lamperti et al., 2021). However, the current empirical result is particularly important as the exposure measure at the bank level is more important than the nationwide vulnerability index that is insignificant.

This result means that the climate risk is not just a matter of severity of weather conditions during the year under consideration. The location of loans, industries that receive financing from the banks, exposure concentration, and disclosure of climate risk are also matters that affect the climate risk of banks. Therefore, it is necessary to introduce a differentiated supervision of banks in relation to the climate risk in prudential regulations.

● Regulatory Implications for the RBI

The first implication for the RBI is the value of bank-level climate-risk measurement. The RBI's work on climate stress testing and climate-risk information already points toward the importance of granular data. CABRF can complement this agenda by translating bank-level exposure into a capital-planning metric. Second, the framework could be used as an additional indicator in supervisory review rather than as an automatic capital requirement. Banks with high CREI could be subject to enhanced climate-risk assessment, scenario analysis, governance review and capital planning.

Third, climate-sensitive capital assessment should be

integrated with disclosure reforms. Standardised climate-risk disclosures can improve the quality of BES and eventually allow sectoral exposure measures to be replaced with borrower-level or facility-level indicators. The RBI's disclosure initiatives therefore have an indirect but important role in making future climate-adjusted prudential models more robust (RBI, 2024b).

● Implications for Commercial Banks

For banks, the findings reinforce the need to integrate climate considerations into portfolio management, credit underwriting and capital planning (Bellinva, Venturelli, Brighi, & Algeri, 2025). Institutions with high exposure to climate-sensitive sectors should not rely exclusively on aggregate climate scenarios. They should identify sectoral and geographical concentrations, assess borrower transition strategies, evaluate collateral vulnerability and incorporate climate information into risk appetite and stress-testing processes.

Climate governance and disclosure also become prudentially relevant. In the present index, governance and disclosure form part of the bank-specific exposure measure. Better disclosure can therefore improve measurement while simultaneously reducing information asymmetry between banks, supervisors and market participants.

● Limitations

The first limitation is sample size. The analysis covers ten major commercial banks and the effective regression sample is 73 observations. Although the banks represent important public- and private-sector institutions, the sample limits statistical power and external validity.

Second, the physical-hazard index is national rather than geographically granular. The same CHI is assigned to all banks in a given year. This limits the ability to connect a specific bank's lending footprint to the physical hazards experienced by its borrowers.

Third, several climate measures are proxies. GNPA is used as a broad credit-risk indicator rather than a true borrower-level PD. Governance and green-finance disclosure scores are based on public reporting and therefore contain measurement risk. The Bank Exposure Score also captures portfolio-level sectoral exposure rather than borrower-specific transition plans.

Fourth, λ is a calibration parameter rather than an independently estimated structural regulatory parameter. The proposed overlay should therefore not be interpreted as a universal capital rule. Larger samples, better climate data and supervisory validation are required before any regulatory adoption could be considered.

Fifth, the empirical specification identifies

conditional associations rather than causal effects. Climate exposure, asset quality and capital adequacy may be jointly influenced by unobserved bank-specific or macro-financial factors. Future research using longer panels, lagged exposure measures, instrumental variables or quasi-experimental designs could address this limitation.

● Future Research

Future research should first validate CABRF across countries and banking systems. Comparative evidence from other emerging Asian markets and developed economies can test whether BES remains more informative than aggregate physical hazard exposure and whether the climate sensitivity parameter requires country-specific calibration.

Second, future studies should integrate borrower-level and geospatial information. Facility-level climate exposure, collateral location, emissions intensity, transition plans and sector-specific pathways would permit direct modelling of climate-adjusted PD and LGD. Third, the framework can be extended to the evolving Basel regulatory framework, including revised credit-risk approaches and output-floor considerations, while retaining the central distinction between supervisory add-ons and minimum Pillar I capital requirements.

Fourth, artificial intelligence and natural language processing can improve the measurement of climate governance and disclosure. Automated analysis of sustainability reports and BRSRs, combined with satellite and geospatial hazard data, could generate more objective and granular bank-level climate-risk measures. Finally, the framework should be extended beyond large commercial banks to cooperative banks, regional rural banks, small finance banks and NBFCs, recognising their different business models and climate-sensitive exposures.

Conclusion

This study examined whether climate-related exposure is associated with capital adequacy in Indian commercial banks and used the evidence to develop a Climate-Adjusted Basel Risk Framework. The results indicate a consistent negative association between CREI and CAR across the principal panel estimators, with the preferred fixed-effects coefficient equal to -2.42 . The decomposition further indicates that bank-specific exposure is the principal driver, while the national physical-hazard component is not independently significant. The relationship is also more evident for total capital than CET1.

These findings have two implications. Empirically, they support the proposition that climate risk is relevant to prudential banking risk and should not be considered solely an ESG or disclosure issue. Conceptually, they suggest that climate-sensitive

capital assessment should be differentiated according to institution-specific exposure. CABRF translates this insight into a transparent supervisory add-on by adjusting RWA according to CREI and deriving a Climate-Adjusted Capital Adequacy Ratio.

The framework should not be interpreted as a replacement for Basel III or as evidence that a universal climate capital charge is immediately necessary. Its immediate practical application is as a supervisory and analytical tool within Pillar II, supporting climate stress testing, capital planning and differentiated supervisory assessment. The approach is particularly relevant for emerging-market banking systems where climate vulnerability is material but borrower-level climate data remain incomplete.

Ultimately, the contribution of CABRF lies in connecting three elements that are often studied separately i.e. climate-risk measurement, bank-level empirical evidence and prudential capital regulation. As climate disclosures, supervisory datasets and modelling techniques improve, the framework can be readjusted and tested across broader samples. Cross-country validation, borrower-level modelling, Basel-regulatory integration and AI-enabled climate-risk measurement represent the next steps toward a more rigorous climate-sensitive banking framework.

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