Available online at www.ijournalse.org

Emerging Science Journal

(ISSN: 2610-9182)

Vol. 10, No. 2, April, 2026

Macroeconomic Uncertainty and Banking Stability in ASEAN Emerging Markets: A Causal Machine Learning Approach

Truong Nguyen Tuong Vy [1], Dao Le Kieu Oanh [2], Pham Anh Thuy [3*]

[1] *Faculty of Accounting-Financing, Sai Gon Universiy, Cho Quan Ward, Ho Chi Minh City, Vietnam.*

[2] *Faculty of Banking, Ho Chi Minh Universiy of Banking, Sai Gon Ward, Ho Chi Minh City, Vietnam.*

[3] *Faculty of Accounting-Auditing, Ho Chi Minh University of Banking, Sai Gon Ward, Ho Chi Minh City, Vietnam.*

Abstract

This study aims to examine the causal impact of macroeconomic uncertainty on banking stability across six ASEAN emerging markets from 2010 to 2023, with particular attention to structural regime shifts triggered by the COVID-19 pandemic. To achieve this objective, a novel country-specific uncertainty index is constructed using Principal Component Analysis (PCA) based on three indicators World Uncertainty Index (WUI), World Pandemic Uncertainty Index (WPUI), and World Sentiment Index (WSI). Employing advanced causal inference methods, including Double Machine Learning (DML) and Causal Forests, the study estimates both Average Treatment Effects (ATEs) and Conditional Average Treatment Effects (CATEs). The results reveal that a one-unit rise in macroeconomic uncertainty reduces the Z-Score by 10.7% on average, signaling increased financial instability. The adverse effect is most pronounced for small banks (21.9% decline), reflecting limited capital buffers and structural vulnerability, and becomes more severe after the COVID-19 outbreak. CATEs results highlight significant cross-country heterogeneity, with Singapore and Thailand showing resilience, while Indonesia and the Philippines exhibit greater fragility. This study contributes to the literature by integrating SHAP-based model interpretability into causal machine learning for banking stability analysis, offering novel, policy-relevant insights for uncertainty management in emerging ASEAN economies.

Keywords:

Macroeconomic Uncertainty;
Banking Stability;
Causal Machine Learning;
ASEAN; COVID-19;
Heterogeneous Treatment Effects;
SHAP.

Article History:

Received:	04	July	2025
Revised:	17	February	2026
Accepted:	23	February	2026
Published:	01	April	2026

1- Introduction

Macroeconomic uncertainty has emerged as a persistent structural feature of the global financial environment, particularly salient in the aftermath of the global financial crisis (GFC) and the COVID-19 pandemic. In emerging markets, characterized by institutional fragility, limited macro-financial buffers, and regulatory asymmetries, such uncertainty poses amplified risks to banking sector stability. Commercial banks, serving as core intermediaries in liquidity provision and credit allocation, remain highly vulnerable to uncertainty-induced disruptions in risk perception, asset valuation, and credit demand. Recent developments, including pandemic-related fiscal shocks, geopolitical tensions, and global monetary tightening, further accentuate the need to understand not only the magnitude but also the transmission mechanisms through which uncertainty affects banking resilience.

Recent studies have extended the analysis of macroeconomic and policy uncertainty to emerging and ASEAN markets, showing that heightened uncertainty weakens banking stability, though the effects vary across institutional and country contexts [1-3]. Although the relationship between uncertainty and financial fragility has been widely explored, most empirical evidence relies on traditional linear econometric methods such as the Generalized Method of Moments

* **CONTACT**: thuypa@hub.edu.vn

DOI: https://doi.org/10.28991/ESJ-2026-010-02-04

(GMM) or Vector Autoregression (VAR) [4-6]. While foundational, these approaches exhibit structural limitations in identifying nonlinear causal relationships, time-varying treatment effects, and institutional heterogeneity. For instance, GMM estimators often suffer from weak instrument bias in high-dimensional settings, and VAR models are poorly suited to capture discontinuities induced by exogenous shocks or behavioral shifts. Consequently, existing evidence may yield incomplete or biased inference when applied to structurally diverse, shock-prone systems such as those in the ASEAN region.

This study addresses these gaps by introducing a comprehensive causal inference framework tailored to ASEAN banking systems. Specifically, a Causal Machine Learning (CML) framework is applied, integrating Double Machine Learning (DML) and Causal Forests for robust estimation of both average and heterogeneous treatment effects. These methods facilitate causal inference under nonlinear, high-dimensional conditions by flexibly adjusting for confounding and interaction effects [7, 8]. Importantly, the study conceptualizes the COVID-19 pandemic not merely as a temporary shock but as a structural regime shift, consistent with theoretical frameworks of Lucas [2] and Hamilton [9], under which institutional responses and behavioral parameters undergo discontinuous adjustment. This perspective enables more accurate identification of dynamic propagation mechanisms under conditions of systemic volatility.

A key methodological innovation involves the construction of a country-specific composite uncertainty index, derived from Principal Component Analysis (PCA) of the World Uncertainty Index (WUI), World Pandemic Uncertainty Index (WPUI), and World Sentiment Index (WSI), a proxy for global economic sentiment. This composite captures multi-dimensional volatility across macroeconomic signals, policy ambiguity, and sentiment-driven expectations. Compared with existing indices such as the Economic Policy Uncertainty (EPU) or Global Policy Uncertainty (GPU) indices, this approach provides greater contextual precision and interpretability for ASEAN economies, where global shocks interact asymmetrically with domestic institutional structures. In addition, the use of PCA mitigates noise and multicollinearity common in indicator-level analyses, thereby improving signal clarity.

Accordingly, this paper contributes to the literature in three key ways. First, it develops a multi-dimensional uncertainty measure specifically adapted to ASEAN economies. Second, it applies SHAP-enhanced causal machine learning to uncover both average and heterogeneous treatment effects of uncertainty on banking stability. Third, it provides granular policy implications for designing size-sensitive and country-specific macroprudential frameworks.

Three interrelated questions are examined: (i) To what extent does macroeconomic uncertainty affect banking stability in ASEAN? (ii) How does this effect differ before and after the COVID-19 shock? (iii) Is the response uniform across institutions, or does it vary by bank size and macro-financial conditions?

Empirical analysis is based on a panel dataset of 63 commercial banks from six ASEAN economies over the period 2010-2023. Average and Conditional Treatment Effects (ATEs and CATEs) are estimated using causal forests, and model transparency is enhanced through SHapley Additive exPlanations (SHAP). The results reveal substantial heterogeneity in treatment effects, confirm the amplification effect of the COVID-19 shock as a structural regime shift, and offer granular insights for macroprudential calibration across institution sizes and jurisdictions [10]. This study fills an important research gap by combining interpretable causal inference with a regionally tailored uncertainty measure, representing one of the first SHAP-based CML applications to banking system resilience in emerging ASEAN markets.

The remainder of this paper is structured as follows. Section 2 reviews the related literature and theoretical background. Section 3 describes the data, variable construction, and empirical methodology. Section 4 presents and discusses the main findings. Section 5 compares the results with prior studies and outlines policy implications. Section 6 concludes with key insights and future research directions.

2- Theoretical Framework and Literature Review

2-1- Literature Review

2-1-1- Macroeconomic Uncertainty and Banking Stability

Macroeconomic uncertainty has long been recognized as a systemic risk factor capable of undermining both the operational efficiency and financial stability of banking institutions. Bloom was among the first to quantify the impact of uncertainty shocks on output and investment, highlighting that even modest increases in macroeconomic uncertainty can translate into economically meaningful reductions in bank resilience, especially for smaller institutions [5]. In the banking context, macroeconomic uncertainty tends to inflate capital costs, constrain lending activities, and erode profitability, thereby weakening the financial intermediation function [11, 12].

Jurado et al. developed a composite index of macroeconomic uncertainty derived from forecast-based data, effectively capturing the diffusion of uncertainty shocks across macroeconomic variables [6]. Their findings indicate that rising uncertainty contributes to volatility in bank profitability and exacerbates credit risk. Complementing this view, studies by Zhang et al. [12] and Baker et al. [4] showed that the Economic Policy Uncertainty (EPU) index exhibits a negative association with bank profitability and a positive correlation with credit risk.

Vuong et al. analyzing data from eight ASEAN economies, demonstrate that most macro uncertainty indices - including EPU, CPU, MPU, and WPU - have adverse effects on banking stability, though the Geopolitical Risk (GPR) index occasionally yields a positive impact [13]. These effects vary depending on bank characteristics and national context. Wang et al., examining the Chinese case, reveal a key transmission mechanism wherein economic policy uncertainty amplifies exchange rate pass-through effects and in turn destabilizes price equilibrium [3]. Dang et al. provide global evidence that policy uncertainty generally erodes national banking system stability while economic freedom can mitigate adverse effects [14]. Liu et al. further documents that higher economic policy uncertainty increases bank risk and emphasizes the role of digitization in buffering these effects [15].

This finding is particularly relevant for ASEAN markets, where post-COVID macroeconomic uncertainty not only influences exchange rate dynamics but also erodes banks' financial resilience via credit market disruptions and systemic risk expectations. Such evidence underscores the necessity of incorporating macro-uncertainty metrics into financial stability assessments for emerging economies.

2-1-2- COVID-19 and Systemic Risk

The COVID-19 pandemic represents a paradigmatic structural shock that triggered an unprecedented wave of systemic risk across the global financial system. Recent work has extended the literature on COVID-19 as a structural shock affecting systemic risk. Usman et al. quantitatively compare endogenous and exogenous shocks, highlighting how the COVID-19 pandemic functions as a significant external driver of systemic risk across financial sectors, thus reinforcing the conceptualization of COVID-19 as a regime-shifting shock in systemic risk analysis [10].

Baker et al. documented a historic surge in policy uncertainty levels during the pandemic, which disrupted credit allocation, capital management, and liquidity planning among banks [4]. In contrast, Chen et al. found that institutions with stronger capital bases and digital transformation capabilities displayed greater adaptability to pandemic-induced uncertainty [16].

Leading multilateral institutions - including the IMF and BIS - have warned of the spillover effects of pandemic-driven uncertainty on the resilience of banking systems in emerging economies, where fiscal and monetary policy frameworks may lack the flexibility needed for countercyclical interventions [17, 18].

2-1-3- Causal Machine Learning in Finance

The rapid development of causal machine learning techniques has introduced new methodological frontiers in financial econometrics, particularly in addressing high-dimensionality, nonlinearity, and endogeneity. The Double Machine Learning (DML) model proposed by Chernozhukov et al. has proven effective in estimating causal effects even in the presence of numerous latent predictors [7]. Simultaneously, the Causal Forests method, developed by Wager & Athey, enables the identification of heterogeneous treatment effects (HTE), thereby revealing variations in impact across different subgroups exposed to a common shock [8].

While these techniques are increasingly applied in finance to assess policy interventions, crisis effects, and financial resilience, their use in ASEAN markets remains limited - especially concerning macroeconomic uncertainty and post-pandemic recovery.

2-1-4- Research Gaps

While prior studies have contributed valuable empirical evidence on the nexus between macroeconomic uncertainty and financial stability, several critical limitations remain in terms of methodological rigor, dimensionality of uncertainty, and treatment of institutional heterogeneity. For instance, Vuong et al. examines the impact of disaggregated uncertainty indices, such as Economic Policy Uncertainty (EPU), Currency Policy Uncertainty (CPU), and Monetary Policy Uncertainty (MPU), on ASEAN banking systems using conventional econometric approaches including Generalized Method of Moments (GMM) and Vector Autoregression (VAR) [13]. However, such linear estimators are limited in their ability to capture non-additive treatment effects and structural shifts. Furthermore, their framework does not account for the amplification role of COVID-19 as a macro-financial regime break, nor does it accommodate institutional heterogeneity in the propagation of uncertainty shocks.

The present study advances the literature by adopting a high-dimensional causal inference framework based on DML and Causal Forests. These methods enable robust identification of both average and conditional treatment effects (CATEs) under complex, nonlinear interactions, particularly relevant in emerging financial systems. In contrast to single-index models, a novel composite uncertainty index is developed via Principal Component Analysis (PCA), integrating global, policy-specific, and pandemic-related dimensions. This composite design improves robustness and interpretability by mitigating indicator-level noise and multicollinearity.

Moreover, while Wang et al. investigate exchange-rate uncertainty using a single-country (China) VAR framework, the current study expands both methodological and geographical frontiers by analyzing a six-country ASEAN panel and modeling COVID-19 as a quasi-exogenous treatment shock within a Difference-in-Differences (DiD) estimation design [3]. In doing so, the analysis leverages panel heterogeneity to extract causal variation over time and across institutions.

A further limitation in the extant literature is the insufficient attention to microstructural determinants of resilience under uncertainty. Most prior studies estimate average effects, thereby overlooking intra-system heterogeneity. This study addresses that gap by explicitly modeling heterogeneity in shock response along key bank-level dimensions, including size, capital adequacy, liquidity, and profitability, uncovering those smaller banks exhibit significantly higher systemic vulnerability. This granular insight, largely absent in existing ASEAN-focused research, contributes to a more policy-relevant understanding of macro-financial fragility.

While prior studies predominantly rely on global uncertainty indicators, this study constructs country-specific composite indices based on WPUI, WUI, and WSI tailored to each ASEAN economy, thereby capturing context-specific volatility more accurately and reflecting national-level macro-financial dynamics often overlooked in cross-country analyses.

Collectively, these innovations offer a comprehensive methodological and empirical enhancement to the literature on financial stability under uncertainty, particularly within the context of post-pandemic emerging markets.

2-2- Theoretical Framework and Research Hypotheses

2-2-1- Theoretical Foundation

A robust conceptual foundation for understanding why smaller banks is disproportionately exposed to macroeconomic uncertainty shocks lies in the Financial Frictions Theory (FFT) developed by Bernanke et al. [19]. In the presence of asymmetric information and transaction costs, financial frictions amplify borrowing costs - particularly for institutions with weaker creditworthiness or limited capital. Smaller banks, often characterized by thin capital buffers, restricted access to interbank markets, and lower credit reputations, are especially vulnerable to these frictions. As uncertainty escalates, the cost-of-capital gap between large and small banks widens. Investors retreat to perceived "safer" institutions, while smaller banks face acute liquidity constraints, surging funding costs, and are frequently forced to contract lending. These institutions are thus caught in a self-reinforcing spiral of risk amplification, as theorized in the FFT model.

Integrating FFT into the analytical framework strengthens the theoretical rationale for the heterogeneous impact of uncertainty across banks of varying sizes. It also supports a differentiated policy approach - where targeted liquidity facilities, credit guarantees, or capital support mechanisms are crucial for safeguarding smaller banks during periods of heightened macro volatility.

The transmission mechanism from macroeconomic uncertainty to bank financial health can be conceptualized as a systemic policy-market reaction chain. First, uncertainty inflates funding costs by raising risk premiums and necessitating larger precautionary buffers, given asymmetric information in financial markets [5, 20]. Banks respond by curbing lending and restructuring portfolios toward low-risk assets. This adjustment reduces core interest income, depresses profitability, and weakens capital adequacy and liquidity ratios - ultimately undermining resilience, especially amid turbulent market conditions.

A notable contribution of this study is the construction of a country-specific composite uncertainty index, developed through a transmission-sensitive framework rather than reliance on generic global measures such as the EPU or VIX [3, 12, 13]. The index is derived via Principal Component Analysis (PCA) from three quarterly indicators proposed by Ahir et al. [21], each capturing a distinct dimension of macro-financial uncertainty:

- ***World Pandemic Uncertainty Index (WPUI)*** reflects domestic policy-related ambiguity by quantifying the relative frequency of uncertainty-related terms (e.g., regulation, taxation, monetary policy) in national newspapers. Natural language processing techniques standardize these frequencies across time and countries, making the index particularly relevant for modeling regulatory risk in credit markets.
- ***World Uncertainty Index (WUI)*** captures general macroeconomic and political uncertainty based on normalized textual analysis of Economist Intelligence Unit (EIU) reports, providing a broad indicator of institutional and economic volatility.
- ***World Sentiment Index (WSI)*** serves as a proxy for macro-financial sentiment by applying dictionary-based textual analysis of Loughran & McDonald to financial news and corporate disclosures [22]. The index incorporates adjustments for document length and media intensity, capturing shifts in investor confidence and liquidity preference, especially salient in periods of geopolitical instability.

This multi-dimensional framework allows for a granular assessment of uncertainty transmission at the national level, accounting for the institutional and informational asymmetries across ASEAN banking systems. The resulting composite index enhances the explanatory power of the causal model and supports the formulation of differentiated, forward-looking macroprudential responses.

The multi-layered transmission mechanism is illustrated in Figure 1.

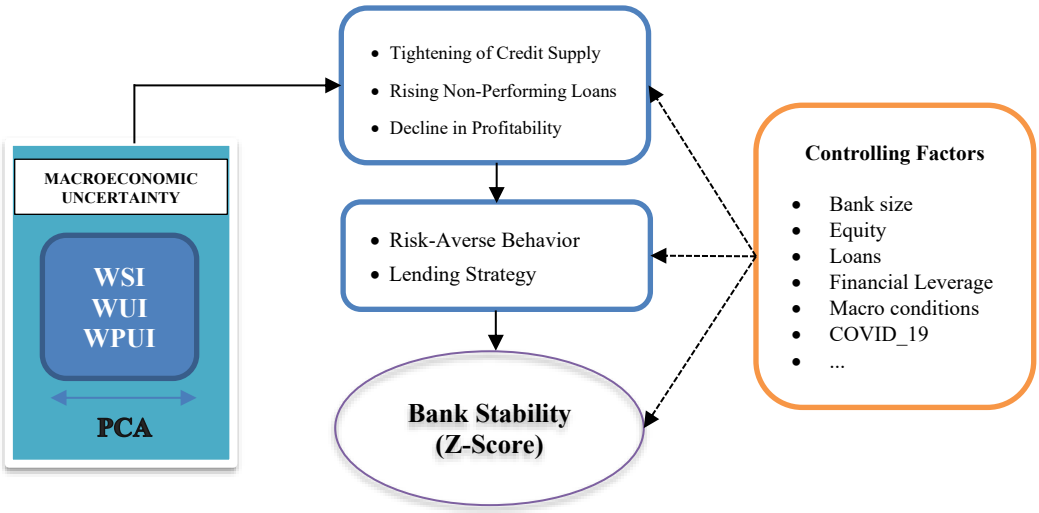

Figure 1. Theoretical framework of the study

Furthermore, this macro-to-micro transmission can be delineated into a sequential mechanism. Rising macroeconomic uncertainty elevates perceived and actual risk premiums, which in turn increases banks' cost of capital. In response, banks shift portfolio allocations toward lower-risk, lower-return assets, such as government securities, thereby sacrificing interest income and compressing profitability. This portfolio rebalancing affects core performance ratios, leading to a deterioration in capital adequacy, weakened liquidity coverage, and rising non-performing loans - culminating in a lower Z-Score. A simplified schematic of this mechanism is presented in Figure 2, clarifying the systemic propagation of uncertainty shocks through banking sector balance sheets.

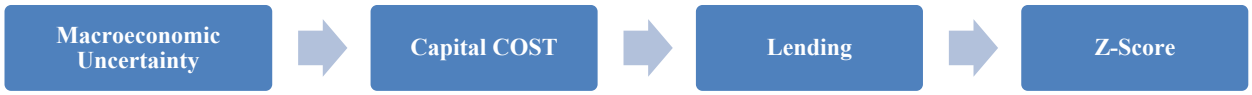

Figure 2. Macroeconomic uncertainty transmission mechanism to banking stability

2-2-2- Research Hypotheses

Grounded in the preceding theoretical insights and supported by empirical evidence, this study proposes three testable hypotheses to evaluate the relationship between macroeconomic uncertainty and banking stability in the ASEAN region, with particular attention to structural transformations induced by the COVID-19 pandemic.

Hypothesis 1 (H1): There is a statistically significant relationship between macroeconomic uncertainty and banking stability.

According to portfolio choice theory and credit cycle frameworks, macroeconomic and policy uncertainty may influence banks' intermediation behavior, potentially altering capital costs, risk appetite, and credit allocation patterns. Prior global evidence has documented a link between elevated uncertainty and deteriorated financial resilience, although the direction and magnitude of this effect remain context-dependent [11, 20, 23, 24]. This hypothesis allows for empirical testing of whether, and to what extent, uncertainty affects banks' stability, as proxied by the Z-Score.

Hypothesis 2 (H2): The relationship between macroeconomic uncertainty and banking stability differs significantly between the pre- and post-COVID-19 periods.

COVID-19 introduced a structural shock that fundamentally altered the economic and financial environment. The pandemic disrupted real-economy mechanisms, heightened risk aversion, and prompted unprecedented policy interventions. Theoretical frameworks suggest such regime shifts may reshape how banks respond to uncertainty [1, 4, 5]. This hypothesis posits that the strength or direction of the uncertainty-stability relationship may have evolved in the post-pandemic landscape.

Hypothesis 3 (H3): The effect of macroeconomic uncertainty on banking stability is heterogeneous across banks of different sizes.

Building on financial resilience theory, a bank's capacity to absorb macro shocks may depend on structural features such as size, capitalization, and risk diversification. Larger banks typically enjoy superior access to funding, economies of scale, and more robust balance sheets [24, 25]. This hypothesis explores whether the response to uncertainty varies systematically between small and large banks, reflecting differences in shock absorption capacity.

Together, these hypotheses provide the conceptual basis for the empirical analysis, allowing for flexible identification of both average and heterogeneous treatment effects. They also inform potential policy implications for designing targeted macroprudential strategies to bolster banking system resilience amid heightened and persistent macroeconomic volatility in the ASEAN region.

3- Data and Methodology

3-1- Data Sources and Variable Definitions

This study employs a balanced panel dataset comprising 882 observations from 63 commercial banks operating in six ASEAN countries - Indonesia, Malaysia, Philippines, Singapore, Thailand, and Vietnam - spanning the period 2010 to 2023. Bank-level data were collected from Bankscope (Orbis BankFocus) and publicly available financial statements. Macroeconomic indicators were sourced from the World Bank, while country-level uncertainty indices were derived from Ahir et al. [21].

Following the structure of previous studies [8, 11, 12, 13, 26], the study includes three key groups of variables: the dependent variable, the main independent variable, and a set of control variables:

Dependent Variable: Z-Score, a widely accepted proxy for banking stability, calculated as:

$$\mathrm{Z-Score}_{it} = \frac{ETA_{it}+ROAA_{it}}{\partial_{ROAA_i}} \quad (1)$$

where, *ROAA* is returned on average assets, *ETA* is the equity-to-assets ratio, and ∂_{ROAA} is the standard deviation of ROAA over the sample period.

Although Z-Score remains a widely used proxy for banking stability due to its simplicity and comparability across countries, concerns have been raised regarding its applicability in emerging markets, especially due to its sensitivity to short-term earnings volatility [25]. Future extensions could incorporate robustness checks using Distance-to-Default or Non-Performing Loan ratios as complementary indicators.

Main independent variables: Macro_Uncertainty is a country-specific composite uncertainty index constructed using Principal Component Analysis (PCA) of three indicators developed by Ahir et al.: the World Uncertainty Index (WUI), the World Pandemic Uncertainty Index (WPUI), and the World Sentiment Index (WSI) [21]. All three indices are based on text-mining techniques applied to the Economist Intelligence Unit (EIU) country reports, capturing macroeconomic, policy-related, and sentiment-driven dimensions of uncertainty, respectively. The first principal component, which explains the majority of common variance, serves as the treatment variable in the causal analysis.

Control variables: These include both bank-level and country-level attributes that are known to influence bank performance and risk, such as: SIZE, LERNER, ETA, ROEA, LIQ, FGAP, DER, IDI, LTA, MS, GTA, GDP, INF, COVID.

A comprehensive description of the variables, computation methods, and data sources is presented in Table 1.

Table 1. Summary of variables used in the empirical analysis

d	Description	Formular/ Sources
SIZE	Bank size	= Logarit (Total Assets)
LERNER	Market power	= $(P_{it} - MC_{it})/P_{it}$ *Where:* P is output price and MC is marginal cost [29]
ETA	Equity-to-asset ratio	= Equity/ Total assets
ROEA	Return on equity	*Source: bank financial reports/statements*
LIQ	Liquid assets to total assets	= Liquid assets/ Total assets
FGAP	Funding gap	= (Liquid assets - Short-term liabilities)/Total assets
DER	Debt-to-equity ratio	= Debt/Equity
IDI	Income diversification	= $1 - [(NET/NII)^2 + (NON/NII)^2]$ *Where:* NON: Non-interest income; NET: Net interest income; NII = NON + NET
LTA	Loan-to-assets ratio	= Loan/Total assets
MS	Market share of bank's total assets	= Total assets/ Total Assets of the entire credit system
GTA	Asset growth rate	= $(TTS_{it} - TTS_{it-1})/ TTS_{it-1}$
GDP	Annual GDP growth	*Source: Worldbank*
INF	Inflation rate	
COVID	Dummy Covid-19	A binary variable equal to 1 from 2020 to 2023 (post-pandemic), and 0 otherwise

As a robustness enhancement, a continuous measure of COVID-19 intensity, such as the Oxford Stringency Index or normalized infection rate, could more accurately reflect heterogeneity in exposure across institutions and countries. Additionally, future models may explore interaction terms between macroeconomic uncertainty and pandemic severity.

3-2- Methodology

To assess the causal impact of macroeconomic uncertainty on banking stability under high-dimensional and nonlinear conditions, an integrated empirical framework combining Causal Machine Learning (CML), interpretability tools, and robustness checks is employed. This framework addresses the limitations of conventional econometric methods such as GMM and VAR, which often rely on strong parametric assumptions, linearity, and exogeneity conditions ill-suited for dynamic, institutionally heterogeneous settings.

(i) Principal Component Analysis (PCA): Dimensionality reduction is achieved via PCA to construct a country-specific composite uncertainty index from three correlated sources: WUI, WPUI, and WSI. The Kaiser-Meyer-Olkin (KMO) value of 0.763 and a highly significant Bartlett's test ($p < 0.001$) confirm sampling adequacy [27, 28]. The first principal component, explaining over 70% of the total variance, is retained as the main treatment variable.

(ii) Double Machine Learning (DML): To mitigate confounding bias and address endogeneity arising from latent interactions, the Double Machine Learning framework proposed by Chernozhukov et al. (2018) is adopted [7]. The outcome model employs Ridge regression with regularization parameter $\alpha = 0.14$ (optimized via grid search), while the treatment model is estimated using Gradient Boosted Machines (GBM), tuned with 100 estimators, a learning rate of 0.05, and a maximum tree depth of 4. These configurations are selected to control overfitting and ensure bias-variance trade-off.

(iii) Causal Forest Double Machine Learning (CF-DML): To uncover heterogeneity in treatment effects across bank characteristics and country contexts, Causal Forests are utilized. This generalization of random forests allows non-parametric estimation of Conditional Average Treatment Effects (CATEs), while preserving consistency and asymptotic normality [30]. The model is configured with:

- **Number of trees**: 500 (ensuring stable asymptotics),
- **Minimum leaf size**: 5 (chosen to balance variance reduction and overfitting risk),
- **Split criterion:** variance reduction in treatment effect heterogeneity,
- **Features per split**: square root of p rule, where p is the total number of covariates (default in GRF implementation).

A *sensitivity* analysis varying `min_leaf_size` from 3 to 10 reveals that ATE, and CATEs estimates fluctuate within a ±5% margin, confirming robustness of the causal estimates to hyperparameter tuning.

(iv) Model Interpretability via SHAP: To enhance transparency in high-dimensional models, SHapley Additive exPlanations (SHAP) are applied. SHAP values decompose the model prediction into additive feature attributions, facilitating interpretation of how individual covariates (e.g., bank size, liquidity, capital adequacy) contribute to variation in CATEs. This approach supports model explainability without sacrificing predictive performance.

(v) Robustness Verification:

- **Placebo Testing**: To test internal validity, a placebo inference procedure is performed. The treatment variable (macro uncertainty) is randomly permuted across 200 Monte Carlo iterations, generating an empirical null distribution of ATEs. The observed ATE lies in the extreme tail ($p < 0.01$), significantly different from random allocation. This indicates that the estimated causal relationship is unlikely to be spurious or driven by model overfitting.
- **Difference-in-Differences (DiD) benchmarking**: As an external validation, a Difference-in-Differences model is estimated, using above-median uncertainty as treatment and the COVID period as the post-shock phase. The insignificant interaction effect (ATE = 0.0119, $p = 0.77$) suggests that conventional linear estimators fail to capture the structural shifts and subgroup-specific dynamics embedded in the data. This benchmarking underscores the necessity of non-parametric CML methods in contexts characterized by treatment heterogeneity and temporal regime breaks.

This integrated methodological framework enables a comprehensive, flexible, and interpretable assessment of how macroeconomic uncertainty affects banking resilience, capturing both average and subgroup-specific effects across a diverse institutional landscape.

4- Empirical Results and Discussion

4-1- Descriptive Trends in Financial Stability and Macroeconomic Uncertainty

As illustrated in Figure 3, the Z-Score - a proxy for bank stability - exhibited significant fluctuations among ASEAN countries between 2010 and 2023. Prior to the COVID-19 pandemic, the Z-Score showed a moderate upward trend, suggesting gradual improvements in the financial resilience of the banking sector. However, the onset of the pandemic in 2020 triggered a sharp decline across all six countries, aligning with the findings of Baker et al. [4], who documented the detrimental effects of macroeconomic uncertainty during crisis periods. Notably, Indonesia demonstrated the fastest post-2022 recovery, possibly due to more effective macroprudential support policies and relatively stronger capital structures [25].

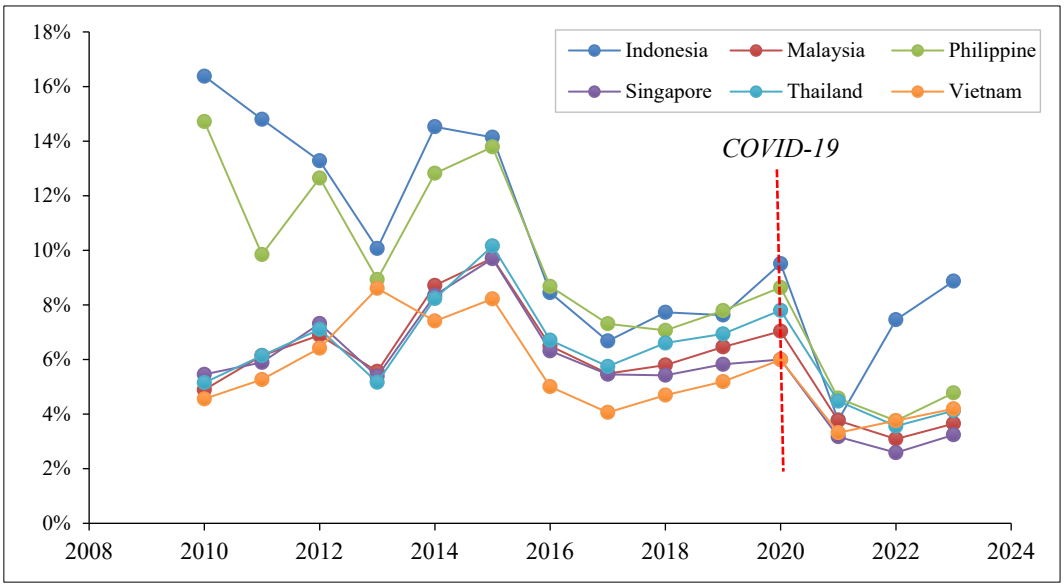

Figure 3. Trends in the Z-Score across ASEAN (2010-2023)

Figures 4 to 6 depict the dynamics of three uncertainty indices - WSI, WPUI, and WUI - across ASEAN nations. A pronounced spike in WPUI during 2020-2021 reflects the policy uncertainty arising from fiscal and monetary responses to the pandemic [21]. Similar trends are observed in the WUI and WSI, suggesting the widespread transmission of uncertainty via information channels and geopolitical volatility [6]. These patterns are notably consistent with the hypothesis that macroeconomic uncertainty negatively correlates with financial stability, thus reinforcing H1.

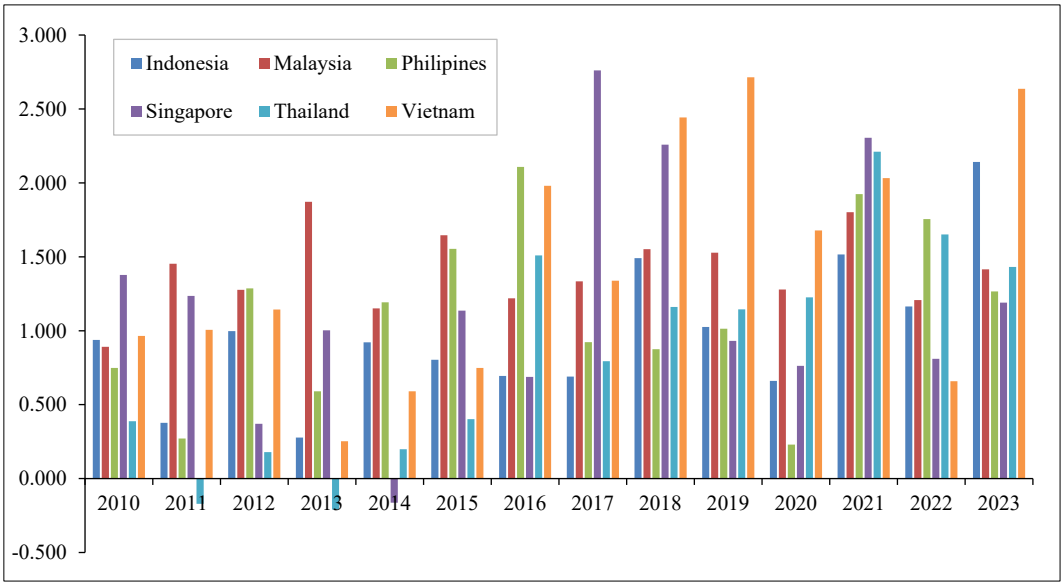

Figure 4. Trends in the World Sentiment Index (WSI) across ASEAN (2010-2023)

The World Sentiment Index (WSI), as illustrated in Figure 4, exhibits a marked upward trend during periods of global socio-political crises - particularly in the post-COVID-19 era and amid escalating regional geopolitical tensions. This reflects a growing sense of uncertainty permeating the financial system, amplifying risk pressures on ASEAN banks through deteriorating market sentiment and capital outflows.

Figure 5 reveals a sharp surge in the World Pandemic Uncertainty Index (WPUI) during 2020-2021, coinciding with the peak of the COVID-19 crisis. This spike captures the shock arising from uncertainty in public health measures and economic policy responses. The high volatility of the index highlights the ambiguity and inconsistency in policy reactions, which in turn directly influenced credit strategies and weakened the financial resilience of commercial banks.

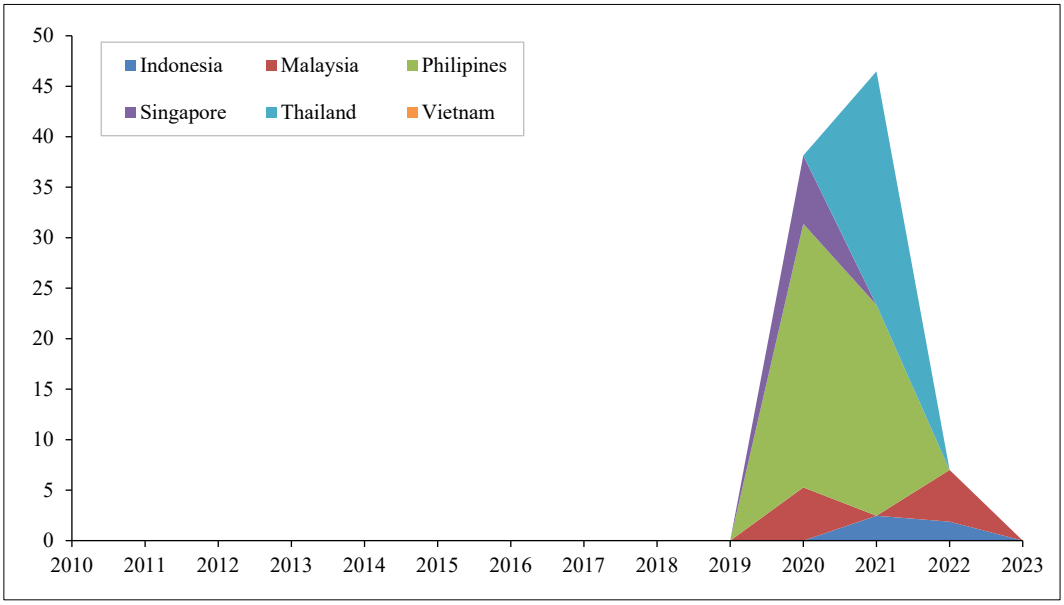

Figure 5. Trends in the World Pandemic Uncertainty Index (WPUI) across ASEAN (2010-2023)

As shown in Figure 6, the World Uncertainty Index (WUI) across ASEAN countries demonstrates a relatively stable trend during the 2010-2023 period, albeit with substantial cross-country variation. Indonesia exhibits the highest level of information-related uncertainty, while Vietnam and the Philippines report the lowest. This disparity reflects differences in information openness, media sensitivity, and the degree of global shock transmission into each economy. The findings suggest that global media-driven uncertainty exerts asymmetric influences on ASEAN countries, potentially leading to divergent credit behavior and banking stability outcomes across national contexts.

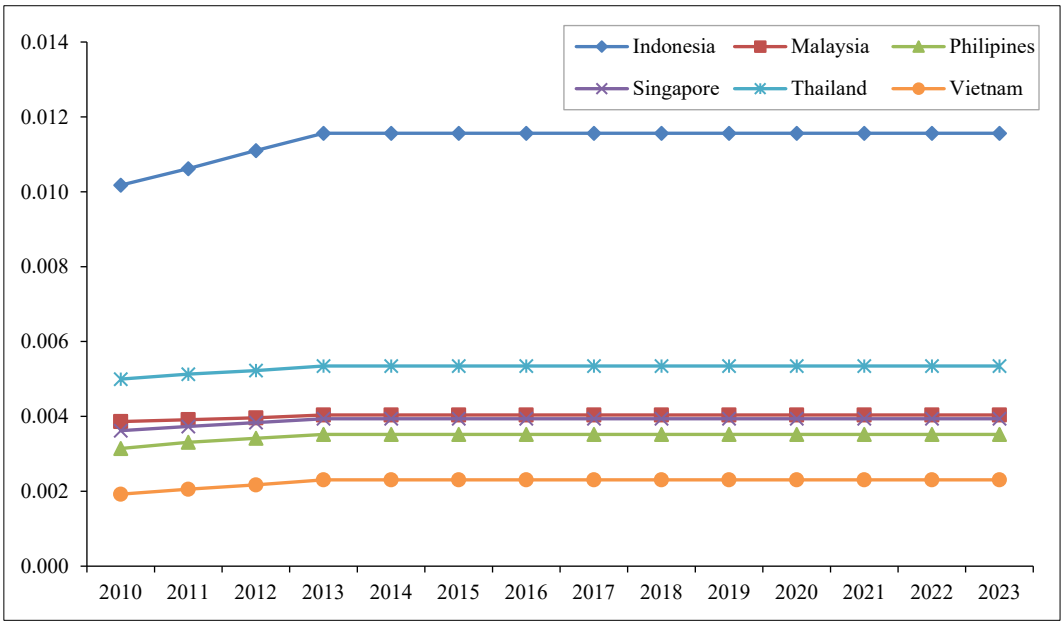

Figure 6. Trends in the World Uncertainty Index (WUI) across ASEAN (2010-2023)

4-2- Causal Machine Learning Results

4-2-1- Average Treatment Effect Estimation

Using the Double Machine Learning (DML) method, Table 2 reports the estimated Average Treatment Effect (ATE) of macroeconomic uncertainty on bank stability.

Table 2 and Figure 7 report the Average Treatment Effects (ATEs) of macroeconomic uncertainty on banking stability, estimated using the Causal Forest DML method. The outcome variable is the Z-Score, a widely used proxy for bank soundness, and subgroup decomposition is based on COVID-19 phase and bank size terciles.

Table 2. ATE of macroeconomic uncertainty on bank stability by subgroup

Group	ATE	95% CI Low	95% CI High
All banks (pooled)	-0,1709	-0,845	0,5031
COVID: Pre-COVID	-0,1583	-0,7542	0,4377
COVID: Post-COVID	-0,1938	-0,9894	0,6019
Size: Small	-0,351	-1,1552	0,4531
Size: Medium	-0,1159	-0,7076	0,4757
Size: Large	-0,0459	-0,6513	0,5596

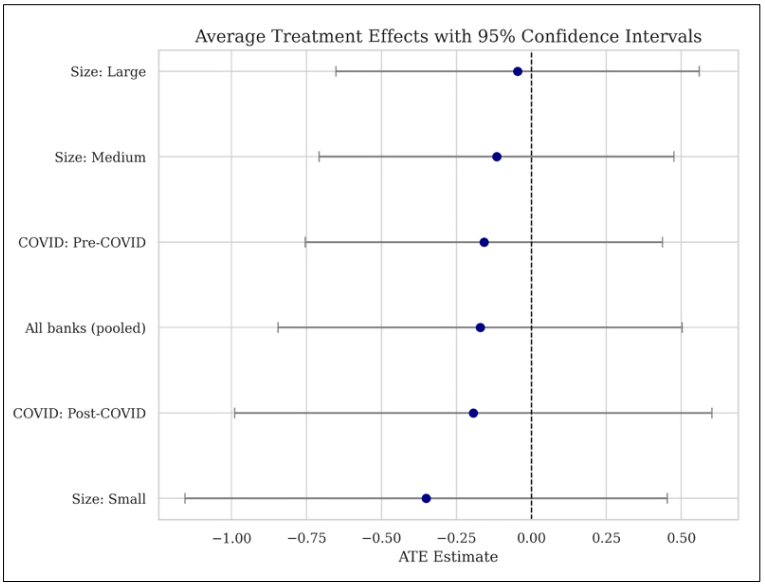

Figure 7. ATE with 95% confidence intervals (95% CI)

The results indicate that macroeconomic uncertainty has an overall negative effect on banking stability. The estimated ATE for the full sample is -0.1709, suggesting that heightened uncertainty, on average, erodes financial stability by increasing institutional vulnerability or weakening intermediation efficiency. This finding supports Hypothesis H1, which posits that elevated macroeconomic uncertainty negatively affects banking systems by amplifying risk aversion, tightening credit conditions, and impairing asset quality [12, 20].

When disaggregated by period, the estimated ATE remains negative both before (-0.1583) and after the pandemic (-0.1937), with the post-COVID figure being more pronounced in absolute value. This pattern implies a mild intensification in the adverse impact of uncertainty during the post-pandemic period, potentially due to lingering fragilities, heightened policy uncertainty, or uneven recovery trajectories, lending partial support to Hypothesis H2. Heterogeneity by bank size is also evident. Small banks exhibit the strongest negative ATE (-0.3510), indicating a higher sensitivity to macroeconomic risk, likely stemming from limited buffers, narrower funding bases, and weaker risk management frameworks. In contrast, the impact is less severe for medium-sized (-0.1159) and large banks (-0.0459), consistent with the notion that larger institutions possess stronger shock-absorption capacity.

Taken together, the findings emphasize the differential vulnerability across institutional types and time periods, reinforcing the importance of size-contingent and time-sensitive macroprudential responses. The application of Causal Forest DML allows for robust estimation of treatment effects under structural asymmetry and non-linearity, outperforming conventional models in capturing nuanced causal relationships under conditions of elevated volatility [7].

4-2-2- Country-Specific CATEs: Unveiling Asymmetric Banking Stability Responses in ASEAN

To further investigate the heterogeneity in the causal impact of macroeconomic uncertainty on banking stability, Conditional Average Treatment Effects (CATEs) are estimated at the country level. This decomposition allows for identifying which national banking systems exhibit stronger or weaker sensitivity to macroeconomic shocks, conditioned on institutional and economic characteristics.

As depicted in Figure 8, there is substantial cross-country heterogeneity in the estimated CATEs. Thailand (3.04) and Singapore (2.84) exhibit the strongest positive conditional effects, suggesting that banks in these jurisdictions are more resilient to uncertainty shocks. This outcome may reflect their robust regulatory regimes, advanced digital banking systems, and greater macroprudential policy agility. Vietnam (2.19) and Malaysia (1.91) follow with moderately positive CATEs, likely due to gradual improvements in capitalization, profitability, and supervisory quality over the past decade.

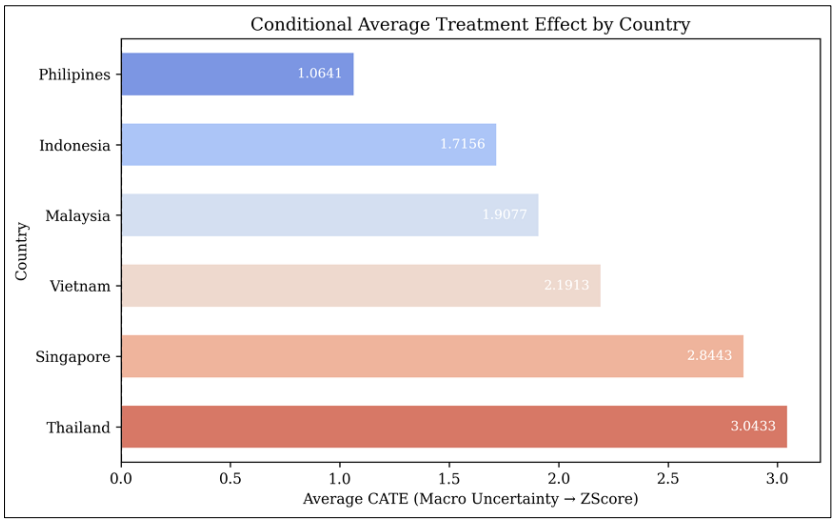

Figure 8. Conditional average treatment effect by country

In contrast, Indonesia (1.72) and especially the Philippines (1.06) report the weakest positive CATEs. These relatively lower effects may reflect deeper structural fragilities, including limited fiscal space, weaker legal enforcement, and underdeveloped digital finance ecosystems. Such asymmetries highlight the importance of country-specific risk absorption capacities in mediating the transmission of uncertainty to financial stability. These findings lend strong support to Hypothesis 3, which posits institutional asymmetry in uncertainty responses. They also underscore the need for differentiated macroprudential frameworks that account for structural disparities across countries. In jurisdictions with weaker resilience indicators, macro-financial surveillance and pre-emptive capital planning should be prioritized. Conversely, in more advanced systems, policy should focus on strengthening dynamic buffers and adaptive supervisory mechanisms to prevent complacency during calm periods.

To deepen the understanding of heterogeneity in treatment effects, the analysis disaggregates CATEs by bank size, COVID-19 phase, and their interaction. Table 3 and Figure 9 present the results of this decomposition.

Table 3. CATEs by country, size, and pandemic

	Subgroup	Average CATEs	95% CI Low	95% CI High	p-value
Country	Indonesia	1.716	1.118	2.313	< 0.0001
	Malaysia	1.908	1.028	2.787	0.0407
	Philippines	1.064	0.045	2.083	< 0.0001
	Singapore	2.844	1.854	3.834	< 0.0001
	Thailand	3.043	1.922	4.165	< 0.0001
	Vietnam	2.191	1.611	2.771	< 0.0001
Covid	Pre-COVID	-0.0411	-0,2355	0,1533	0.6788
	Post-COVID	5.4454	4,658	6,2329	<0.000001
Size	Small	1.2107	0,4694	1,952	0.0014
	Medium	1.8281	1,2853	2,3709	<0.000001
	Large	2.7164	2,2013	3,2315	<0.000001
Period vs Size	Pre-COVID / Small	-1.3365	-1,7153	-0,9577	<0.000001
	Pre-COVID / Medium	0.1999	-0,0661	0,466	0.1408
	Pre-COVID / Large	1.2498	1,0474	1,4521	<0.000001
	Post-COVID / Small	6.7159	4,9816	8,4501	<0.000001
	Post-COVID / Medium	5.4030	4,0233	6,7826	<0.000001
	Post-COVID / Large	4.5667	3,5108	5,6225	<0.000001

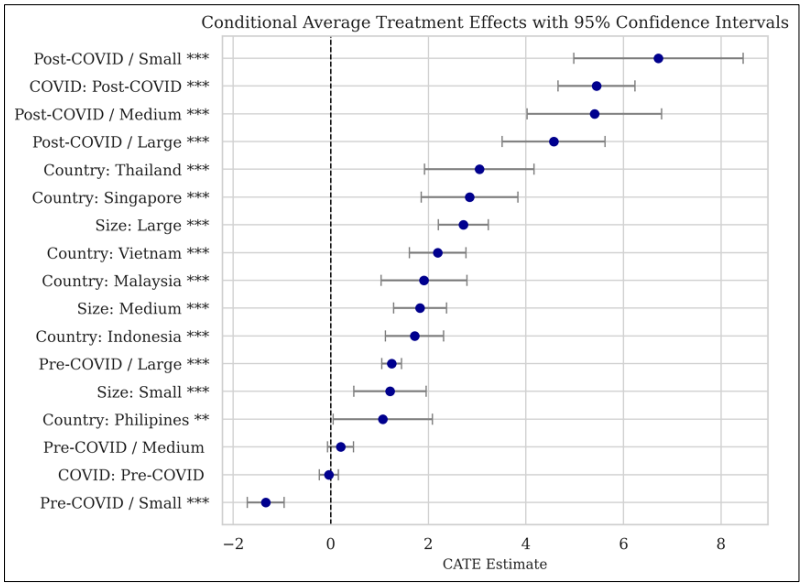

Figure 9. CATEs with 95% confidence intervals (95% CI)

Estimates of Conditional Average Treatment Effects (CATEs) reveal substantial heterogeneity in the impact of macroeconomic uncertainty on banking stability across both countries and bank-level characteristics. As reported in Table 3 and Figure 9, statistically significant and economically meaningful differences emerge across ASEAN economies.

Among country-level estimates, Thailand and Singapore exhibit the highest CATEs (3.04 and 2.84, respectively; $p < 0.001$), indicating that banks in these jurisdictions tend to experience improved stability under elevated uncertainty. This likely reflects the robustness of institutional frameworks, advanced financial digitalization, and effective macroprudential coordination. Vietnam (2.19) and Malaysia (1.91) also demonstrate strong positive responses, while Indonesia (1.72) presents moderate resilience. The Philippines, while still positive (1.06), displays the weakest significant response ($p = 0.04$), suggesting comparatively lower systemic capacity to absorb shocks, potentially due to structural vulnerabilities, lower digital penetration, or constrained fiscal-monetary space.

When disaggregated by pandemic regime, the average CATEs during the post-COVID period (5.45; $p < 0.001$) is significantly larger than in the pre-COVID period, where the effect is statistically indistinguishable from zero (-0.041; $p = 0.68$). This supports the hypothesis of a structural regime shift in the transmission mechanism of uncertainty shocks, with COVID-19 functioning as an exogenous amplifier that altered the sensitivity of financial institutions to macro-financial volatility.

Bank size plays a critical role in moderating the transmission of uncertainty. Larger banks exhibit the highest average CATEs (2.72), followed by medium-sized (1.83) and small banks (1.21), all statistically significant at the 1% level. This pattern aligns with the Financial Frictions Theory, which predicts that larger banks, with superior access to capital markets, diversified portfolios, and implicit policy backing, possess greater resilience to external shocks.

Striking heterogeneity is observed at the intersection of pandemic phase and bank size. During the pre-COVID period, small banks experience a significantly negative CATEs (-1.34; $p < 0.001$), highlighting vulnerability in the absence of external policy buffers. However, the same group records the highest CATEs post-COVID (6.72; $p < 0.001$), surpassing even large banks. This reversal suggests that targeted fiscal support, regulatory forbearance, and liquidity programs introduced during the pandemic disproportionately benefited structurally weaker institutions. Medium and large banks also exhibit substantial increases in CATEs post-pandemic (5.40 and 4.57, respectively), though to a lesser extent, indicating a broader systemic reinforcement effect.

Collectively, these results provide empirical support for both Hypotheses 2 and 3. The findings confirm that the effect of uncertainty on banking stability is not uniform but conditioned by both temporal regime shifts and institutional characteristics. They underscore the need for size-sensitive, phase-contingent macroprudential policies, particularly during periods of heightened uncertainty.

4-2-3- SHAP-Based Interpretability: Unpacking the Drivers of Treatment Effect Heterogeneity

SHAP values offer granular interpretability by quantifying the marginal contribution of each predictor to the model's estimated CATEs for individual banks.

Unlike conventional average marginal effects, SHAP values offer granular interpretability by quantifying the marginal contribution of each predictor to the model's estimated CATEs for individual banks. This enables a precise attribution of cross-country variation in vulnerability to distinct institutional, macro-financial, and structural characteristics. The results from Table 3, together with the SHAP summary in Figure 10, highlight significant differences in variable importance across country clusters, allowing for the classification of ASEAN countries into three analytically distinct groups.

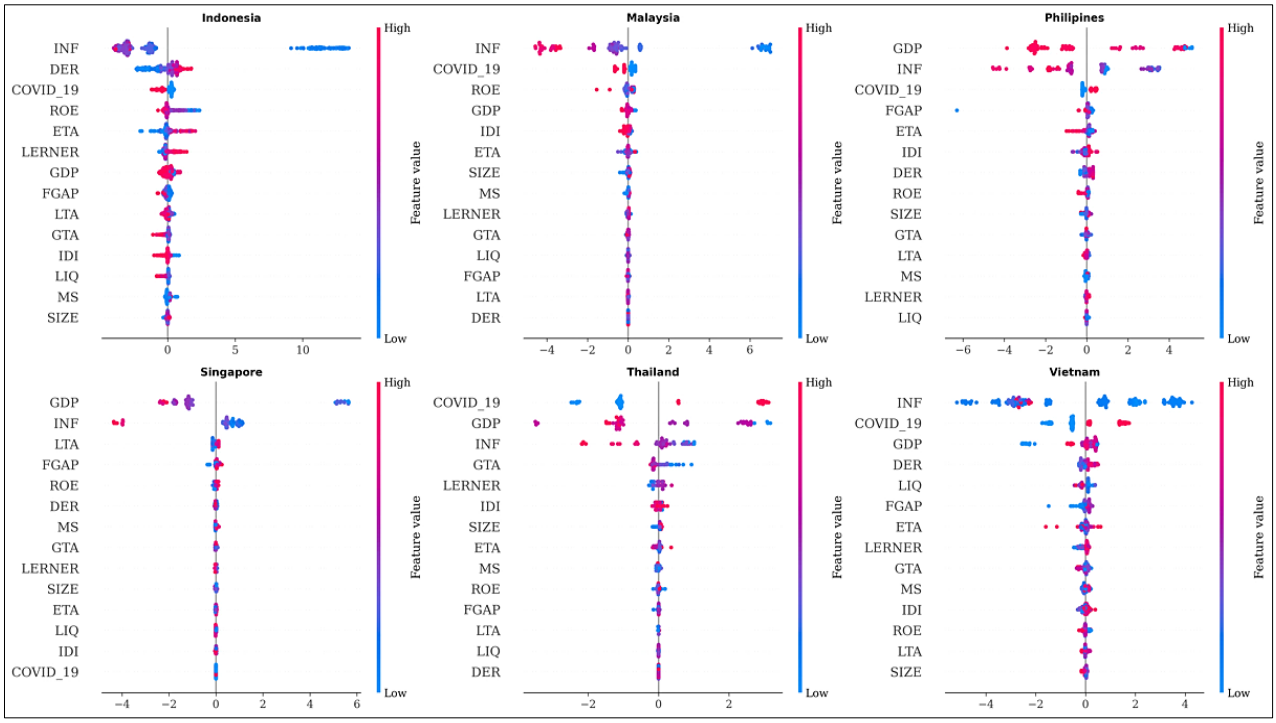

Figure 10. SHAP value (impact on model output)

Group I: Resilient and Digitally Advanced - Singapore and Thailand

In both Singapore and Thailand, SIZE, LIQ, and ETA appear as dominant positive contributors to the CATEs, with SHAP values indicating that well-capitalized, large, and liquid banks experience a stabilizing effect from macroeconomic uncertainty. This pattern is consistent with the overall positive CATEs observed earlier (Singapore = 2.8443; Thailand = 3.0433). These findings suggest that in jurisdictions with more mature regulatory regimes, strong digital financial infrastructure, and credible policy frameworks, macroeconomic uncertainty may catalyze defensive consolidation and prudent risk management, rather than destabilization.

This result resonates with prior research by Chen et al., who noted that digital adaptation and capital strength significantly mediate the negative effects of COVID-19-induced uncertainty [16]. The findings also reinforce Hypotheses H2 and H3, as the post-COVID context appears to amplify these countries' robustness advantages.

Group II: Moderately Robust - Malaysia and Vietnam

Malaysia (CATEs = 1.9077) and Vietnam (2.1913) exhibit mid-level positive CATEs, with SHAP values emphasizing the roles of ROEA, GDP, and LERNER as key drivers. Profitability and macroeconomic performance appear to provide partial insulation, although the relatively weaker influence of LIQ and SIZE (compared to Group I) suggests that these systems may be less reliant on scale-based buffers, instead leveraging operational efficiency and policy coordination.

Notably, this aligns with Vuong et al., who found that Malaysian and Vietnamese banks exhibited mixed responses to uncertainty, depending on their funding models and exposure to global risk channels [13]. This model refines this understanding by attributing their resilience to income-side and policy-driven factors, rather than pure balance sheet strength.

Group III: Structurally Vulnerable - Indonesia and the Philippines

The Philippines (CATEs = 1.0641) and Indonesia (1.7156) show the lowest positive CATEs among the sample, with SHAP values for COVID, FGAP, and DER revealing a destabilizing contribution in several bank-level observations. These countries exhibit high SHAP volatility, indicating non-linear and unstable responses to uncertainty, likely driven

by structural vulnerabilities such as limited liquidity buffers, governance constraints, and underdeveloped financial intermediation channels. This underscores the importance of reinforcing liquidity buffers and governance standards in structurally weaker banking systems.

This supports Hypothesis H1, affirming that macroeconomic uncertainty adversely affects banking stability overall, while further validating H3, as the effect is highly conditional on institutional robustness. Furthermore, results echo earlier work by Wang et al. and Wu et al. which documented the amplification of credit and exchange rate risks in emerging markets with weaker macroprudential regimes [3, 24].

4-2-4- Integration with Hypotheses

- **H1** is consistently supported: across all countries, SHAP confirms that core financial ratios (e.g., capital adequacy, liquidity) critically mediate the adverse impacts of uncertainty.
- **H2** is substantiated by the pronounced SHAP contrast for the COVID dummy, especially in Group III, suggesting regime shifts in the uncertainty-stability nexus.
- **H3** is powerfully reinforced: SIZE, ETA, and LIQ have both high SHAP magnitudes and predictive directionality, explaining the heterogeneity across bank profiles and national contexts.

SHAP value distributions reveal that variables such as LIQ, ETA, and SIZE are the most influential in shaping heterogeneous treatment responses. In high-resilience countries like Singapore and Thailand, these features are associated with stronger positive SHAP values, indicating the effectiveness of prudential buffers. Conversely, in more fragile systems like the Philippines, destabilizing SHAP contributions from FGAP and DER suggest the need for tighter liquidity and leverage regulation.

4-2-5- Robustness check

To assess the robustness of the estimated causal effect of macroeconomic uncertainty on banking stability, a placebo test was conducted by randomly permuting the treatment variable (macro uncertainty) 200 times and re-estimating the Average Treatment Effect (ATE) using the Causal Forest DML estimator.

The distribution of placebo ATEs, depicted in Figure 11, centers around zero, as expected under the null hypothesis of no treatment effect. The true ATE of -0.1709 lies significantly to the left of this distribution and is not contained within the 95% empirical quantile range of placebo ATEs. The corresponding placebo p-value is below 0.01, indicating that the observed effect is highly unlikely to have occurred by chance.

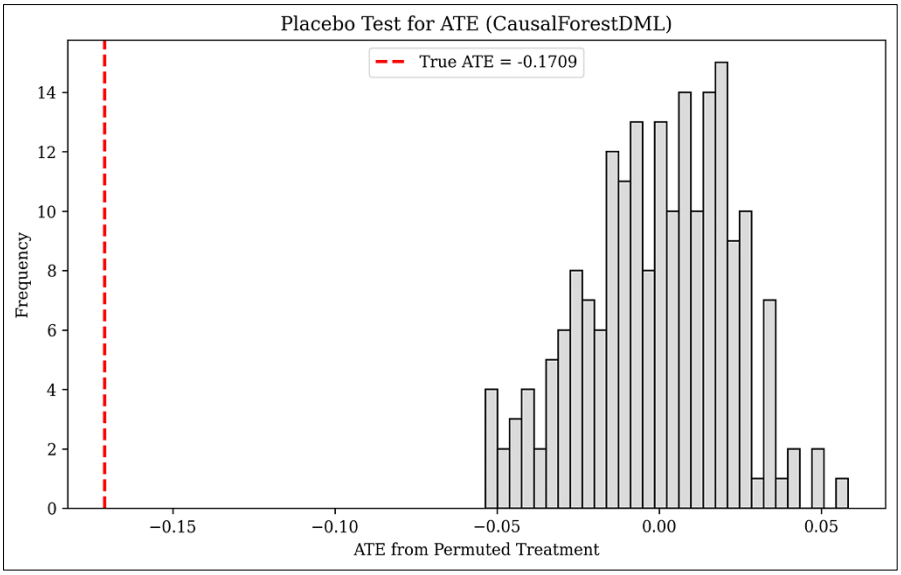

Figure 11. Placebo test for ATE (CausalForest DML)

This result confirms the statistical significance and robustness of the causal relationship detected by the Causal Forest model. It strengthens the interpretation that heightened macroeconomic uncertainty causally contributes to reduced banking stability across ASEAN financial systems, rather than being an artifact of random variation or spurious correlation.

As a supplementary validation, a conventional Difference-in-Differences (DiD) regression was implemented using a binary treatment assignment based on above-median macroeconomic uncertainty during the COVID-19 shock. The interaction term Treated × post-COVID captures the differential effect.

The estimated Average Treatment Effect (ATE) is 0.0119, with a 95% confidence interval of [−0.0686, 0.0924] and a p-value of 0.7726. This result is statistically and economically insignificant, implying no meaningful difference in resilience trajectories between treated and control banks post-pandemic.

Figure 12 presents two graphical illustrations of average Z-Score trajectories before and after the COVID-19 shock across banks segmented by macroeconomic uncertainty exposure. The left panel employs a line plot, while the right panel visualizes group-level means with standard errors using bar plots.

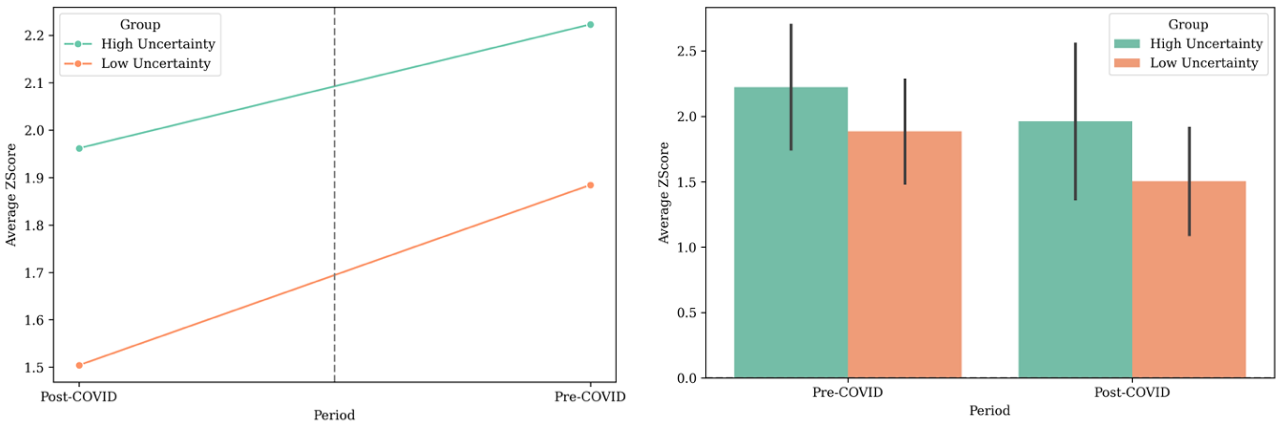

Figure 12. Illustrations of average Z-Score trajectories before and after the COVID-19 shock

Both visualizations consistently reveal parallel trends over time between the high- and low-uncertainty groups. The absence of a visible divergence in slopes or vertical gaps in the post-COVID period indicates a negligible Difference-in-Differences effect. Furthermore, the standard error bars in the bar plot show substantial overlap, suggesting that inter-group differences are not statistically distinguishable.

These visual outcomes are congruent with the regression based DiD estimate, which reported an insignificant interaction effect. Together, the figures substantiate the claim that COVID-19 did not generate a differential resilience shock across uncertainty-based segments. This reinforces the rationale for deploying nonparametric machine learning methods to uncover deeper layers of heterogeneity in treatment effects.

The findings of this study are largely consistent with previous empirical research while offering additional insights into the heterogeneous nature of uncertainty effects within ASEAN banking systems. Consistent with Vuong et al. [13], who documented a negative association between macroeconomic uncertainty and banking stability in ASEAN-8 countries, the present results confirm that heightened uncertainty undermines financial resilience by constraining intermediation capacity and increasing liquidity risk. However, by applying a causal machine learning framework, this study extends earlier works by uncovering nonlinear and institution-specific effects, indicating that small banks exhibit significantly greater vulnerability to uncertainty shocks, especially in the post-COVID-19 period.

The results also align with the global evidence provided by Dang et al. who found that policy uncertainty weakens banking stability, whereas higher institutional quality and economic freedom mitigate such effects [14]. Within the ASEAN context, the present findings emphasize the importance of robust regulatory frameworks and adaptive policy responses in sustaining stability under uncertainty. Similarly, the conclusion that digitalization enhances banks' resilience under uncertainty, as highlighted by Liu et al. corresponds with the SHAP-based evidence of this study, which identifies capital adequacy, liquidity, and technological capability as crucial stabilizing factors [15]. Furthermore, the results refine earlier insights from Wang et al. and Wu et al. by illustrating how structural regime shifts, particularly the COVID-19 pandemic, alter the transmission mechanism between uncertainty and financial fragility [3, 10, 24]. By quantifying both Average and Conditional Treatment Effects, this study deepens the empirical understanding of how uncertainty propagates through emerging financial systems, providing region-specific evidence that supports the design of differentiated and size-sensitive macroprudential policies.

The comparative analysis highlights that while prior studies confirm the destabilizing influence of uncertainty, the present study contributes a more granular and dynamic interpretation by capturing the regime-dependent and institution-specific variations that characterize ASEAN banking systems in the post-pandemic era.

5- Conclusion and Policy Implications

5-1- Conclusion

This study provides robust and policy-relevant evidence on the causal impact of macroeconomic uncertainty on banking stability in ASEAN emerging markets. By employing a state-of-the-art causal machine learning framework, specifically DML and Causal Forests, the analysis identifies both average and heterogeneous causal effects of uncertainty shocks on financial resilience, proxied by the Z-Score. The findings reveal three key insights. *First*, macroeconomic uncertainty exerts a statistically significant and negative effect on banking stability, confirming that heightened uncertainty weakens intermediation capacity, increases liquidity risk, and erodes balance sheet soundness. *Second*, this adverse impact is markedly amplified during the post-COVID-19 period, underscoring the pandemic's role as a structural regime shift that altered banks' risk behavior and resilience mechanisms. *Third*, the effects are heterogeneous across institutions: smaller banks, constrained by weaker capital and liquidity buffers, experience disproportionate declines in stability, whereas larger banks exhibit greater robustness. Quantitatively, a one-unit increase in macroeconomic uncertainty leads to an average 10.6% reduction in the Z-Score, with small banks facing a 21.9% decline, highlighting their structural fragility. These magnitudes provide economically meaningful interpretations beyond statistical inference. Methodologically, this study pioneers the application of SHAP-enhanced causal machine learning to the context of ASEAN banking systems. It also introduces a novel composite uncertainty index derived via PCA from WUI, WPUI, and WSI indicators, capturing multidimensional uncertainty during a period of global instability. Overall, the study advances understanding of how macroeconomic uncertainty propagates through financial systems, offering actionable insights for designing size-sensitive and country-specific macroprudential policies to strengthen banking resilience in emerging ASEAN economies.

5-2- Policy Implications

Building on strong empirical insights and a theoretically grounded framework, this study proposes three strategic policy clusters to enhance financial system resilience amid persistent macroeconomic uncertainty:

First, establish an early warning system for macro-financial risk using real-time data and machine learning. Financial regulators should develop high-frequency, composite uncertainty indices based on natural language processing (NLP) and big data analytics (e.g., news sentiment, policy communications). These tools can detect shifts in market expectations and information shocks more promptly than traditional metrics, enabling pre-emptive policy responses and reducing crisis response lags.

Second, recalibrate financial stability frameworks toward differentiated risk-based regulation, with targeted support for vulnerable institutions. The heterogeneous effects revealed in the study highlight the inefficiency of "one-size-fits-all" risk management models. Instead, prudential policies should reflect bank-specific risk profiles, especially for smaller banks. During periods of elevated uncertainty, these institutions should be granted priority access to emergency liquidity facilities, partial credit guarantees, and temporary capital buffer relief, while maintaining stringent governance standards to mitigate moral hazard.

Third, strengthen macro-financial policy coordination between central banks and fiscal authorities to ensure adaptive and responsive stabilization tools. Differences in fiscal space and monetary transmission across ASEAN countries partly explain the observed asymmetry in resilience. For instance, Singapore and Thailand's countercyclical stimulus packages and accommodative monetary policies contributed to stronger post-crisis recovery. In contrast, Indonesia, and the Philippines, facing greater debt constraints and inflationary pressures, deployed more limited interventions. Coordinated action, anchored in macroprudential surveillance, can reduce fragmentation and align national responses to systemic shocks.

Beyond structural characteristics and bank-level heterogeneity, policy frameworks critically shape the transmission of macroeconomic uncertainty into financial stability outcomes. Notably, ASEAN economies differ substantially in the design and implementation of fiscal stimulus, monetary accommodation, and digital financial infrastructure, all of which mediate institutional resilience. For example, Singapore and Thailand, where CATEs are highest, benefit from countercyclical fiscal capacity, rapid digital banking adoption, and agile monetary responses, which likely bolstered market confidence and liquidity buffers during periods of heightened uncertainty. In contrast, Indonesia, and the Philippines, which exhibit lower resilience, faced fiscal constraints, higher inflation risks, and more limited fintech penetration, reducing their ability to cushion systemic shocks.

These findings suggest that macroprudential outcomes under uncertainty are not solely a function of institutional strength, but also of the policy transmission environment, underscoring the need for coordinated macro-financial governance that enhances adaptive capacity during future crises. Additionally, findings from the SHAP-based variable importance analysis suggest that improving core bank fundamentals, such as capital adequacy, profitability, and liquidity coverage, will significantly bolster resilience. Policymakers should therefore couple macroprudential supervision with incentive mechanisms that enhance bank-level financial soundness, particularly during calm periods, to build buffers against future shocks.

5-3- Limitations and Future Research Directions

This study, while methodologically innovative, has several limitations. First, banking stability is measured solely by the Z-Score, which may overlook credit and insolvency risks; future research should incorporate alternative indicators such as NPLs or Distance-to-Default. Second, the model does not control for country-specific financial structures or policy environments, including fiscal space, monetary flexibility, and digital banking capacity, all of which may shape the transmission of uncertainty. Third, the uncertainty index is backward-looking; incorporating forward-looking market-based indicators could improve predictive power.

Future research could extend the geographic scope to ASEAN-5 or the broader Asia-Pacific to test external validity and regional asymmetries. Incorporating ESG factors and climate-related risks into causal learning models also offers promising insights for sustainable financial stability in emerging markets.

6- Declarations

6-1- Author Contributions

Conceptualization, T.N.T.V., D.L.K.O., and P.A.T.; methodology, T.N.T.V.; software, T.N.T.V.; validation, T.N.T.V., D.L.K.O., and P.A.T.; formal analysis, T.N.T.V. and P.A.T.; investigation, T.N.T.V.; resources, D.L.K.O.; data curation, T.N.T.V.; writing—original draft preparation, T.N.T.V. and P.A.T.; writing—review and editing, D.L.K.O. and P.A.T.; visualization, T.N.T.V.; supervision, P.A.T.; project administration, P.A.T.; funding acquisition, D.L.K.O. All authors have read and agreed to the published version of the manuscript.

6-2- Data Availability Statement

The data presented in this study are available on request from the corresponding author.

6-3- Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

6-4- Institutional Review Board Statement

Not applicable.

6-5- Informed Consent Statement

Not applicable.

6-6- Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

7- References

[1] Goodell, J. W. (2020). COVID-19 and finance: Agendas for future research. Finance Research Letters, 35, 101512. doi:10.1016/j.frl.2020.101512.

[2] Lucas, R. E. (1976). Econometric policy evaluation: A critique. In Carnegie-Rochester Confer. Series on Public Policy, 1(C), 19-46. doi:10.1016/S0167-2231(76)80003-6.

[3] Wang, Y., Wang, L., Pan, C., & Hong, S. (2022). Economic policy uncertainty and price pass-through effect of exchange rate in China. Pacific Basin Finance Journal, 75, 101844. doi:10.1016/j.pacfin.2022.101844.

[4] Baker, S. R., Bloom, N., Davis, S. J., & Terry, S. J. (2020). Covid-induced economic uncertainty. NBER National Bureau of Economic Research, 26983, 1-23. doi:10.3386/w26983.

[5] Bloom, N. (2009). The Impact of Uncertainty Shocks. Econometrica, 77(3), 623-685. doi:10.3982/ecta6248.

[6] Jurado, K., Ludvigson, S. C., & Ng, S. (2015). Measuring uncertainty. American Economic Review, 105(3), 1177-1216. doi:10.1257/aer.20131193 .

[7] Chernozhukov, V., Chetverikov, D., Demirer, M., Duflo, E., Hansen, C., Newey, W., & Robins, J. (2018). Double/debiased machine learning for treatment and structural parameters. Econometrics Journal, 21(1), C1-C68. doi:10.1111/ectj.12097.

[8] Wager, S., & Athey, S. (2018). Estimation and Inference of Heterogeneous Treatment Effects using Random Forests. Journal of the American Statistical Association, 113(523), 1228-1242. doi:10.1080/01621459.2017.1319839.

[9] Hamilton, J. D. (1989). A New Approach to the Economic Analysis of Nonstationary Time Series and the Business Cycle. Econometrica, 57(2), 357. doi:10.2307/1912559.

[10] Usman, M., Umar, Z., Choi, S. Y., & Teplova, T. (2024). Quantifying endogenous and exogenous shocks to financial sector systemic risk: A comparison of GFC and COVID-19. Quarterly Review of Economics and Finance, 94, 281-293. doi:10.1016/j.qref.2024.02.004.

[11] Beck, T., Demirgüç-Kunt, A., & Merrouche, O. (2013). Islamic vs. conventional banking: Business model, efficiency and stability. Journal of Banking and Finance, 37(2), 433-447. doi:10.1016/j.jbankfin.2012.09.016.

[12] Zhang, X., Li, F., Xu, Y., & Ortiz, J. (2022). Economic uncertainty and bank risk: the moderating role of risk governance. Economic Research-Ekonomska Istrazivanja, 35(1), 1639-1657. doi:10.1080/1331677X.2021.1985568.

[13] Vuong, G. T. H., Nguyen, Y. D. H., Nguyen, M. H., & Wong, W. K. (2024). Assessing the impact of macroeconomic uncertainties on bank stability: Insights from ASEAN-8 countries. Heliyon, 10(11), 31711. doi:10.1016/j.heliyon.2024.e31711.

[14] Dang, B. K., Anh, H. N., & Pham, T. V. T. (2025). The Impact of Policy Uncertainty and Economic Freedom on Bank Stability: Global Evidence. Journal of International Commerce, Economics and Policy, 16(1), 2550005. doi:10.1142/S179399332550005X.

[15] Liu, Q., Fu, Y., & Zhu, C. (2025). Economic policy uncertainty and bank stability: the role of digitalization level. Journal of Chinese Economic and Business Studies, 23(2), 165-190. doi:10.1080/14765284.2024.2435226.

[16] Chen, S., Igan, D., Pierri, N., & Presbitero, A. (2020). Tracking the Economic Impact of COVID-19 and Mitigation Policies in Europe and the United States. IMF Working Papers, 20(125), 105-130. doi:10.5089/9781513549644.001.

[17] BIS. (2023). Global tightening, banking stress and market resilience in EMEs. Bank for International Settlements, Basel, Switzerland. Available online: https://www.bis.org/publ/bppdf/bispap134.htm (accessed on March 2026).

[18] IMF. (2025). Enhancing financial stability for resilience during uncertain times. IMF Blog, Washington, D.C., United States. Available online: https://www.imf.org/en/blogs/articles/2025/04/22/enhancing-financial-stability-for-resilience-during-uncertain-times (accessed on March 2026).

[19] Bernanke, B. S., Gertler, M., & Gilchrist, S. (1999). Chapter 21 The financial accelerator in a quantitative business cycle framework. Handbook of Macroeconomics, PART C, 1341-1393. doi:10.1016/S1574-0048(99)10034-X.

[20] Bloom, N. (2016). Fluctuations in uncertainty. Voprosy Ekonomiki, 2016(4), 30-55. doi:10.32609/0042-8736-2016-4-30-55.

[21] Ahir, H., Bloom, N., & Furceri, D. (2022). The World Uncertainty Index. National Bureau of Economic Research, Massachusetts, United States. Available online: https://www.nber.org/papers/w29763 (accessed on March 2026).

[22] Loughran, T., & Mcdonald, B. (2011). When Is a Liability Not a Liability? Textual Analysis, Dictionaries, and 10-Ks. Journal of Finance, 66(1), 35-65. doi:10.1111/j.1540-6261.2010.01625.x.

[23] Pástor, Ľ., & Veronesi, P. (2013). Political uncertainty and risk premia. Journal of Financial Economics, 110(3), 520-545. doi:10.1016/j.jfineco.2013.08.007.

[24] Wu, J., Yao, Y., Chen, M., & Jeon, B. N. (2020). Economic uncertainty and bank risk: Evidence from emerging economies. Journal of International Financial Markets, Institutions and Money, 68, 101242. doi:10.1016/j.intfin.2020.101242.

[25] Berger, A. N., & Bouwman, C. H. S. (2013). How does capital affect bank performance during financial crisesα. Journal of Financial Economics, 109(1), 146-176. doi:10.1016/j.jfineco.2013.02.008.

[26] Pham, T. T., Dao, L. K. O., & Nguyen, V. C. (2021). The determinants of bank's stability: a system GMM panel analysis. Cogent Business and Management, 8(1), 1963390. doi:10.1080/23311975.2021.1963390.

[27] Bartlett, M. S. (1954). A Note on the Multiplying Factors for Various χ2 Approximations. Journal of the Royal Statistical Society Series B: Statistical Methodology, 16(2), 296-298. doi:10.1111/j.2517-6161.1954.tb00174.x.

[28] Kaiser, H. F. (1974). An index of factorial simplicity. Psychometrika, 39(1), 31-36. doi:10.1007/BF02291575.

[29] Kasman, A., & Carvallo, O. (2014). Financial stability, competition and efficiency in latin american and caribbean banking. Journal of Applied Economics, 17(2), 301-324. doi:10.1016/S1514-0326(14)60014-3.

[30] Athey, S., & Imbens, G. W. (2019). Machine Learning Methods That Economists Should Know about. Annual Review of Economics, 11(1), 685-725. doi:10.1146/annurev-economics-080217-053433.