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ORIGINAL ARTICLE

Prudential management of Brazilian banks: Key variables under Basel III

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ABSTRACT

This study examines the determinants of capital adequacy in Brazilian commercial banks, focusing on how internal performance indicators from the CAMELS (capital adequacy, asset quality, management quality, earnings, liquidity, and sensitivity to market risk) framework and macroeconomic conditions shape prudential capital buffers under Basel III. Although capital regulation plays a central role in emerging economies, the literature offers limited evidence on the joint influence of CAMELS dimensions and macroeconomic factors on banks' excess capital positions. Moreover, few studies explicitly address the dynamic and endogenous nature of prudential capital adjustment, particularly in the Brazilian context. Understanding the drivers of banks' capital buffers provides insights into the effectiveness of Basel III in strengthening financial resilience and informs regulatory debates in developing economies. Quarterly panel data from 15 Brazilian commercial banks from 2018 to 2024 are analyzed using traditional panel estimators and dynamic approaches based on difference and system generalized method of moments, allowing for endogeneity, persistence, and intertemporal adjustment. The dependent variable is defined as the difference between the observed capital adequacy ratio and the regulatory minimum. The results indicate that asset quality and profitability positively affect capital buffers, while leverage and inflation exert robust negative effects. Other factors, including liquidity, market risk sensitivity, bank size, and economic growth, display specification-sensitive results, highlighting the role of dynamic adjustment and feedback effects. Overall, capital buffers reflect a prudential and dynamic process rather than purely contemporaneous decisions. The findings contribute to the prudential regulation literature and provide insights for regulators and bank managers regarding risk-based supervision and capital planning in emerging economies.

Keywords: capital adequacy, CAMELS, capital requirements, Basel III.

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Gestão prudencial dos bancos brasileiros: variáveis-chave sob Basileia III

RESUMO

Este estudo examina os determinantes da adequação de capital nos bancos comerciais brasileiros, com foco em como os indicadores internos de desempenho da estrutura CAMELS (adequação de capital, qualidade dos ativos, qualidade da gestão, ganhos, liquidez e sensibilidade ao risco de mercado) e as condições macroeconômicas moldam o capital prudencial adicional sob o Acordo de Basileia III. Embora a regulamentação de capital desempenhe um papel central nas economias emergentes, a literatura oferece evidências limitadas sobre a influência conjunta das dimensões CAMELS e dos fatores macroeconômicos nas posições de capital excedente dos bancos. Além disso, poucos estudos abordam explicitamente a natureza dinâmica e endógena do ajuste prudencial de capital, particularmente no contexto brasileiro. Compreender os fatores determinantes dos adicionais de capital dos bancos fornece insights sobre a eficácia do Acordo de Basileia III no fortalecimento da resiliência financeira e contribui para os debates regulatórios nas economias em desenvolvimento. Dados de painel trimestrais de 15 bancos comerciais brasileiros de 2018 a 2024 são analisados utilizando estimadores de painel tradicionais e abordagens dinâmicas baseadas no método de momentos generalizados por diferença e por sistema, permitindo endogeneidade, persistência e ajuste intertemporal. A variável dependente é definida como a diferença entre o índice de adequação de capital observado e o mínimo regulatório. Os resultados indicam que a qualidade dos ativos e a rentabilidade afetam positivamente a adequação de capital, enquanto a alavancagem e a inflação exercem efeitos negativos robustos. Outros fatores, incluindo liquidez, sensibilidade ao risco de mercado, tamanho do banco e crescimento econômico, apresentam resultados sensíveis à especificação, destacando o papel do ajuste dinâmico e dos efeitos de retroalimentação. De modo geral, os valores de capital adicional refletem um processo prudencial e dinâmico, em vez de decisões puramente contemporâneas. Os resultados contribuem para a literatura sobre regulamentação prudencial e fornecem insights para reguladores e gestores bancários sobre supervisão baseada em risco e planejamento de capital em economias emergentes.

Palavras-chave: *adequação de capital, CAMELS, requisitos de capital, Basileia III.*

1. INTRODUCTION

Ensuring the stability of banking institutions is essential to preserving the soundness of the financial system. Identifying the determinants of banks' financial performance and resilience provides valuable insights for regulatory and managerial decision-making, particularly during periods of crisis or heightened instability (Demirgüç-Kunt et al., 2013).

In this context, the Basel Accords represent a major milestone in prudential banking regulation. The adoption of Basel III in Brazil from 2013 onward reinforced capital adequacy as a central pillar of solvency and operational continuity. As a result, capital adequacy has become a key indicator of bank soundness and is frequently incorporated into empirical applications of the CAMELS (capital adequacy, asset quality, management quality, earnings, liquidity, and sensitivity to market risk) framework (Abreu & Camargos, 2022; Akhtar et al., 2024; Nugroho et al., 2020).

The CAMELS model evaluates financial institutions across six dimensions – capital adequacy, asset quality, management quality, earnings, liquidity, and sensitivity to market risk (Sahajwala & Van den Bergh, 2000) – and is widely employed in international studies (Bhattarai, 2020; Gharaibeh, 2023; Hunjra et al., 2020; Thach & Pham, 2022). However, empirical evidence on the interaction between CAMELS dimensions and macroeconomic conditions in explaining prudential behavior in Brazilian banks remains scarce.

Accordingly, this study examines how bank-specific factors, captured by the non-capital CAMELS dimensions, and macroeconomic variables influence the quality of capital in Brazilian commercial banks. The results indicate that higher credit quality, greater profitability, and lower leverage are positively associated with prudential management, while inflationary pressures and gross domestic product (GDP) growth exhibit a negative relationship with capital adequacy.

Beyond its academic contribution, the findings offer practical implications for regulators and bank managers by supporting the calibration of capital requirements and strategic decisions aimed at balancing profitability, risk, and regulatory compliance within the Brazilian banking system.

2. THEORETICAL BACKGROUND

2.1 Basel Accords

In response to the financial instability of the 1970s, marked by exchange rate liberalization and increased market volatility, the G-10 countries established the Committee on Banking Supervision and Regulatory Practices at the Bank for International Settlements. The Committee aimed to define minimum supervisory standards to enhance financial stability, although its agreements have no legal force and depend on implementation by national authorities (Oliveira & Ferreira, 2018).

This initiative culminated in the Basel I Accord in 1988, which introduced minimum capital requirements and standardized the measurement of credit risk, defined as the possibility that borrowers fail to meet their financial obligations (Basel Committee on Banking Supervision [BCBS], 1988). The Accord established the concept of risk-weighted assets, differentiated capital into two tiers, and set a minimum capital adequacy ratio (CAR) of 8%.

In 1996, Basel I was revised to incorporate market risk and additional capital buffers . Market risk refers to potential losses resulting from fluctuations in asset prices). The revision also emphasized the role of internal controls, ethical conduct, and supervisory oversight, recognizing the inherent instability of financial markets (BCBS, 1996).

The New Basel Accord (Basel II), introduced in 2004, further expanded the framework by incorporating operational risk, defined as losses arising from human error, system failures, external events, or fraud (BCBS, 2004). According to Peppe (2006), Basel II was structured around three pillars: minimum capital requirements (Pillar I), supervisory review (Pillar II), and market discipline through enhanced disclosure (Pillar III). Unlike Basel I, the new framework required continuous monitoring of banking operations and risk exposures.

The global financial crisis of 2008 revealed limitations of Basel II, particularly the assumption that financial institutions could adequately price and manage their own risks. In response, Basel III was introduced in 2010, strengthening capital requirements, increasing the resilience of large institutions, and introducing capital conservation buffers to absorb losses during crises (Oliveira & Ferreira, 2018).

Despite these advances, a core element has remained unchanged across the Basel Accords: the requirement for a minimum ratio between regulatory capital and risk-weighted assets, known as the Basel index or capital adequacy index. Under Basel III standards (BCBS, 2011), this ratio is calculated based on tier 1 and tier 2 capital relative to assets weighted by credit, market, and operational risks. Table 1 summarizes the main characteristics of tier 1, tier 2, and core capital.

Table 1
Summary of the characteristics of core capital, tier 1 capital and tier 2 capital within the Basel III context

Aspect	Core capital	Tier 1 capital	Tier 2 capital
Quality	Highest quality	High quality, but includes hybrid instruments	Lower quality compared to tier 1
Components	Common shares, reserves, and retained earnings	Common equity tier 1 + hybrid instruments (additional tier 1), such as perpetual convertible bonds	Subordinated instruments, such as subordinated debt securities
Availability	Immediately available to cover losses	Available, but may be subject to conversion or write-down clauses	Available for loss absorption in the event of liquidation or bankruptcy
Loss absorption capacity	Absorbs losses continuously during operation	Absorbs losses in crises, depending on contractual clauses	Absorbs losses in the event of insolvency or liquidation
Examples of instruments	Common shares, profit, and capital reserves	Instruments comprising the principal capital and convertible perpetual securities	Subordinated debt securities with fixed maturity and limited amortization
Objective	Ensure operational stability and resilience	Provide additional support in times of crisis	Offer an extra cushion to absorb extreme losses

Source: *Elaborated by the authors based on BCBS (2011).*

Tier 1 capital comprises high-quality instruments, including core capital, such as common equity and retained earnings, and additional tier 1 instruments, such as hybrid securities. Tier 2 capital includes less resilient instruments, such as subordinated debt and general provisions. Risk-weighted assets are calculated by assigning different risk weights to asset classes according to their risk profile, and the CAR, or Basel Index, is formally defined in Eq. 1.

$$Basel\ Index = \frac{Tier\ 1\ Capital + Tier\ 2\ Capital}{Risk\ Weighted\ Assets} \quad (1)$$

Originally, banks were required to maintain a minimum Basel Index of 8%, meaning that the bank's highest-quality capital had to be at least 8% of the total value of its risk-weighted assets. However, this minimum requirement is generally increased in each country to ensure greater security for the financial system (Oliveira & Ferreira, 2018).

Under Basel III, this adjustment reflects the introduction of capital buffers, which require banks to hold additional capital beyond the minimum requirement. These buffers include the capital conservation buffer, aimed at absorbing losses during periods of stress; the countercyclical buffer, designed to mitigate procyclical behavior by strengthening capital positions during economic expansions; and the systemic buffer, applied to systemically important institutions to reduce the risk of widespread financial instability.

Thus, the value of the Basel Index from the third version onward began to recognize the need for national adaptations to this index, and in some cases, even specific values for banks with greater relevance to the National Financial System. In the next section, this agenda is discussed specifically for the Brazilian scenario.

2.2 Basel Index in Brazil

In the Brazilian context, the National Financial System agency responsible for enforcing the guidelines of the agreements, as well as stipulating the minimum value of the Basel Index, is the Banco Central do Brasil (BACEN). As shown in Table 2, it can be seen that as new versions of the agreements were published, the minimum capital levels and Basel Index values were changed in order to more effectively protect the banking system.

Brazil's adherence to Basel III began in 2013, and national capital requirements have historically exceeded the 8% international benchmark. According to BACEN reports, the minimum ratio of tier 1 and tier 2 capital to risk-weighted assets has remained at approximately 10.5% since 2016. Moreover, Table 2 shows that IFDATA data indicate a current Basel Index for the National Financial System of around 15.8%, signaling a level of capital protection well above regulatory minima and reflecting the overall soundness of the Brazilian banking system (BACEN, 2013).

Furthermore, it is also interesting to highlight the application of capital buffers in national banks. According to the data in Table 3, it is possible to identify that there is currently no additional margin due to countercyclical buffers, with only the capital conservation buffer of 2.5% and the systemic buffer of 1% being applied to banks relevant to the national system.

On this topic, it is important to note that, although theoretically, since 2016, there has been a countercyclical buffer provision, it has always remained at zero, while the capital conservation buffer has always been applied at the maximum amount allowed each year. Thus, although the required index could be 13%, historically, it has always been 10.5% for Brazilian banks in general and 12.5% for systematically important banks.

Finally, it is important to comment on the classification of banks according to BACEN in terms of their systemic importance. There are a total of five possible classification levels, ranging from S1 (Segment 1), which, as mentioned above, groups the most relevant banks for the country, to S5, which, in turn, encompasses financial institutions with a simplified risk profile. Table 4 shows the characteristics that BACEN uses to classify banks.

Table 2
Evolution of minimum capital requirements, tier 1 capital, and Basel index for national banks

	Basel I (%)	Basel II (%)	Basel III (%)
Core capital	4.70*	2.00*	7.00-9.00
Tier 1 capital	5.50*	4.00*	8.50-11.00
Basel index	11.00	8.00	10.50-13.00

** = implied values, since Basel I and II did not differentiate between core capital and tier 1 capital.*
Source: *Adapted from BACEN (2013).*

Table 3
Current limits and values of capital buffers for Brazilian commercial banks

	Maximum limits (%)					Current buffer values (%)
	Until 2015	**2016**	**2017**	**2018**	**From 2019**	**2024**
Capital conservation	0.00	0.63	1.25	1.88	2.50	2.50
Countercyclical	0.00	0.63	1.25	1.88	2.50	0.00
Systemic	0.00	0.00	0.50	1.00	2.00	1.00*
Maximum total	0.00	1.30	3.00	4.80	7.00	3.50*

** = applicable to systemically important banks classified as S1 (Segment 1) – multiple banks, commercial banks, investment banks, foreign exchange banks, and savings banks that (i) have a size (exposure/gross domestic product) greater than 10% or (ii) engage in significant international activity (assets abroad greater than US$10 billion).*
Source: *Elaborated by the authors based on BACEN data.*

Table 4
Criteria for segmenting financial institutions from S1 to S5

Segmentation	Type of financial institution	Characteristics
S1	Banking financial institutions	Size greater than or equal to 10% of GDP or engages in significant international activities
S2	Banking and non-banking financial institutions	Size between 10% and 1% of GDP
S3	Banking and non-banking financial institutions	Size between 1% and 0.1% of GDP
S4	Banking and non-banking financial institutions	Size less than 0.1% of GDP
S5	Non-bank financial institutions	Size less than 0.1% of GDP, and which do not carry out repurchase agreements, issue credit securitization securities, stock exchange transactions, or margin services, and which do not have assets subject to market risk

GDP = gross domestic product.
Source: *Elaborated by the authors based on BACEN data.*

2.3 National Literature

The Brazilian literature on bank capital adequacy has progressively emphasized regulatory compliance, financial stability, and the role of capital buffers as prudential instruments rather than mere regulatory constraints. Early studies highlight that excess capital above the regulatory minimum functions as a mechanism to mitigate insolvency and systemic risk.

Belém and Gartner (2016) provide one of the most direct analyses of capital buffers in Brazil. Using a dynamic panel approach, the authors show that banks adjust their buffers gradually over time, reflecting adjustment costs and persistence in capitalization decisions. Their findings indicate that higher-risk banks tend to hold larger buffers, consistent with prudent risk-management behavior.

Complementing this evidence, Carvalho and Dantas (2021) examine the interaction between market discipline and capital buffers, defining the buffer as the difference between observed capital and the regulatory minimum. The results show that market pressures affect banks' capitalization decisions and highlight the endogenous relationship between capital levels and market discipline.

Other contributions explore the use of CAMELS indicators for prudential assessment. Rosa and Gartner (2018), for instance, develop an early warning model based on CAMELS variables and demonstrate that capital adequacy, asset quality, management efficiency, profitability, and liquidity are significant predictors of financial distress. Although not focused on capital buffers, their results reinforce the relevance of CAMELS dimensions in assessing bank soundness in Brazil.

More recently, a BACEN report (2022) documents how macroeconomic shocks, particularly in the post-COVID period, affected Brazilian banks through CAMELS-related channels. The deterioration in asset quality and higher funding costs exerted pressure on earnings, while stronger treasury results partially offset these effects. Despite these challenges, regulatory capital ratios remained well above minimum requirements, and stress tests indicate that capital and liquidity buffers would remain sufficient even under adverse macroeconomic scenarios.

Finally, studies such as Takahashi and Vasconcelos (2022) highlight that, notably, Brazilian banks' capital adequacy ultimately has a negative impact on their technical efficiency. This reinforces the idea that while a higher level of capitalization ensures greater financial strength against economic shocks, it also restricts the efficiency of financial institutions.

Overall, the Brazilian literature provides valuable insights into bank capitalization, risk, and prudential indicators. However, most studies either focus on capital buffers without integrating the full set of CAMELS dimensions or analyze CAMELS indicators without explicitly modeling capital buffers and their dynamic adjustment. Moreover, evidence combining CAMELS indicators and macroeconomic variables within a dynamic framework, particularly under Basel III, remains limited. This gap motivates the present study, which seeks to integrate these strands through a dynamic analysis of capital buffers in Brazilian commercial banks.

2.4 International Literature

The international literature provides extensive evidence on how bank-specific characteristics and macroeconomic conditions interact to determine capital adequacy across different regulatory and institutional environments. Results from emerging economies are notably heterogeneous, reflecting differences in banking structures and supervisory frameworks.

Several studies document the relevance of liquidity as a key determinant of the CAR. Bhattarai (2020), analyzing Nepali banks, finds a positive effect of liquidity on CAR, while bank size and inflation exert negative impacts; similar results are reported by Ünvan (2020) for Ghana.

This role of liquidity as a prudential buffer is consistent with earlier evidence from Shrieves and Dahl (1992), who identify a positive association between changes in risk and capital. From a macroprudential perspective, Ding and Ding (2024) show that supervisory tools effectively curb systemic risk and procyclical leverage, reinforcing the importance of regulation in shaping banks' capital positions.

Other contributions extend the analysis beyond CAR by explicitly examining capital buffers. Le et al. (2022), focusing on Vietnamese banks, find that leverage, balance sheet expansion, liquidity, profitability, and bank size negatively affect both capital adequacy and excess capital. Evidence from African banking systems similarly highlights the importance of CAMELS-related variables. Abba et al. (2018) show that profitability, asset quality, bank risk, and deposit levels positively influence CAR in Nigerian banks.

Management quality and operational efficiency have also been linked to capitalization. Lotto (2018) documents a positive relationship between capital adequacy and efficiency in Tanzanian banks. However, as emphasized by Kwan and Eisenbeis (1997), capitalization, efficiency, and risk-taking are jointly determined, suggesting simultaneity and feedback effects rather than a unidirectional causal relationship.

Evidence from Southeast Europe indicates that both bank-specific and environmental factors play a significant role. Aktas et al. (2015) show that size, profitability, leverage, and liquidity significantly affect CAR in commercial banks from ten countries, a result corroborated by Keqa (2021). Macroeconomic conditions also matter: Mili et al. (2014) and Schaeck and Čihák (2012) identify positive associations between economic growth and CAR, underscoring the role of the broader economic and institutional environment.

Comparative studies further emphasize the role of regulation and market discipline. Hunjra et al. (2020), analyzing banks from seven developing Asian countries, find that stronger capital regulation and market discipline reduce risk and enhance capital adequacy, with a negative relationship between bank risk and CAR, later confirmed by Lappay et al. (2021) for Indian banks. Focusing on Vietnam, Thuong et al. (2024) and Thach and Pham (2022) report that loans, credit loss provisions, liquidity, and profitability positively affect CAR, whereas bank size, inflation, and GDP growth have negative effects, highlighting the trade-off between balance sheet growth and prudential management.

Finally, Gharaibeh (2023) documents both short- and long-run relationships between CAR and bank-specific variables in Jordanian banks. Short-run dynamics link CAR to leverage, liquidity, credit-to-deposit ratios, and lagged profitability, while long-run estimates show positive effects of leverage and liquidity and a negative impact of the coverage ratio. Table 5 summarizes the main relationships identified in the international literature.

Overall, the empirical evidence indicates a strong alignment between banks' capital adequacy and their risk management strategies, suggesting that capital adequacy reflects not only regulatory compliance but also banks' responses to their operating and risk environments. While there is broad consensus regarding the relevance of liquidity and profitability as key determinants of CAR, the effects of variables such as bank size, GDP growth, and leverage remain mixed across studies. Notably, the determinants most frequently associated with capital adequacy are closely related to the CAMELS dimensions, reinforcing the relevance of this framework for assessing bank performance and prudential behavior.

Table 5
Summary of CAR determinants

Dimension analyzed	Impact on CAR	Studies that concluded this impact
Liquidity	Positive	Aktas et al. (2015), Belém and Gartner (2016), Bhattarai (2020), Carvalho and Dantas (2021), Gharaibeh (2023), Hunjra et al. (2020), Shrieves and Dahl (1992)
Bank size	Negative	Bhattarai (2020), Thach and Pham (2022), Thuong et al. (2024)
	Positive	Aktas et al. (2015), Keqa (2021)
Inflation rate	Negative	Bhattarai (2020), Thach and Pham (2022), Thuong et al. (2024)
GDP growth	Positive	Mili et al. (2014), Schaeck and Čihák (2012)
	Negative	Thach and Pham (2022), Thuong et al. (2024)
Management quality	Positive	Kwan and Eisenbeis (1997), Lotto (2018)
Earnings	Positive	Abba et al. (2018), Aktas et al. (2015), Bhattarai (2020), Gharaibeh (2023), Thach and Pham (2022)
Asset quality	Positive	Abba et al. (2018), Thach and Pham (2022)
Risk	Negative	Aktas et al. (2015), Carvalho and Dantas (2021), Hunjra et al. (2020), Keqa (2021), Lappay et al. (2021)
	Positive	Abba et al. (2018), Belém and Gartner (2016)
Leverage	Positive	Gharaibeh (2023)
	Negative	Aktas et al. (2015), Thach and Pham (2022)

CAR = capital adequacy ratio; GDP = gross domestic product.
Source: *Elaborated by the authors.*

3. METHODOLOGY

3.1 Sample

This study investigates the bank-specific and macroeconomic constraints affecting the CAR of Brazilian commercial banks. Quarterly data were obtained from the BACEN's IFData database. Although the initial dataset comprised 64 institutions with reported commercial activities, the final sample was restricted to 15 banks whose primary business is commercial banking, ensuring greater homogeneity and analytical focus.

The sample includes six publicly controlled banks, eight domestically owned private banks, and one foreign-controlled institution. In regulatory terms, five banks are classified as S1, one as S2, five as S3, and four as S4, thus encompassing institutions with different sizes and levels of systemic relevance. All bank-level information follows BACEN's prudential reporting standards.

Given the focus on the updated capital adequacy framework introduced with Basel III in Brazil, the sample period spans from 2018, when the transition to the new regulatory requirements was already underway, to the end of 2024, totaling 27 quarters. In addition to bank data, macroeconomic data on the Broad Consumer Price Index (*Índice Nacional de Preços ao Consumidor Amplo* [IPCA]) and GDP were also collected from the BACEN and IPEAData databases.

3.2 Econometric Model

As discussed earlier, banks' capital adequacy is shaped by both macroeconomic and bank-specific factors. On the macroeconomic side, the analysis includes inflation (INF) and economic growth (GDP) as key determinants of CAR. In addition, a COVID-19 dummy variable (COVID) is introduced to control for the systemic shock associated with the pandemic, assuming the value of one from the second quarter of 2020 to the first quarter of 2021. This period corresponds to the most severe phase of economic disruption in Brazil and to the implementation of exceptional macroprudential and regulatory measures that affected banks' operating conditions and risk exposure.

Regarding internal determinants, the CAMELS framework is employed to assess how capital adequacy (C) is influenced by the remaining dimensions. This approach is consistent with the prudential management perspective underlying the Basel Accords, which emphasize asset quality, management quality, earnings, liquidity, and sensitivity to market risk. Asset quality is proxied by the non-performing loans ratio (NPL), following Abba et al. (2018), while management quality is captured by the overhead cost ratio (OCR), as in Gharaibeh (2023). Profitability is measured by return on risk-weighted assets (RORA), and liquidity is assessed using the share of liquid assets (LIQ), as proposed by Thach and Pham (2022), and the leverage ratio (LEV), following Gharaibeh (2023) and Ünvan (2020). Sensitivity to market risk is captured by the risk-weighted asset ratio (RAR), consistent with Abba et al. (2018). Bank size (SIZE), measured as the natural logarithm of total assets, is included as a control variable. Table 6 summarizes all variables used in the analysis.

Based on these variables, a panel data model was developed using Eq. 2, which illustrates the traditional pooled modeling approach. It is worth noting that, instead of analyzing the total CAR value of banks, we analyzed the percentage difference between each bank's CAR value and the minimum value stipulated by BACEN (DPCAR).

$$DPCAR_{i,t} = \alpha + \beta_1 NPL_{i,t} + \beta_2 OCR_{i,t} + \beta_3 RORA_{i,t} + \beta_4 LIQ_{i,t} + \beta_5 LEV_{i,t} + \beta_6 RAR_{i,t} + \beta_7 SIZE_{i,t} + \beta_8 GDP_t + \beta_9 INF_t + \beta_{10} COVID_t + e_{i,t} \quad (2)$$

Initially, pooled ordinary least squares (OLS), fixed-effects, and random-effects models were estimated, and F-tests, Lagrange multiplier tests, and Hausman tests were employed to identify the most appropriate statistic specification (Wooldridge, 2010). However, standard panel estimators rely on the exogeneity of regressors, an assumption often violated when accounting-based variables are used, potentially leading to biased and inconsistent estimates (Zhou et al., 2014).

To address endogeneity concerns, the analysis proceeds with dynamic panel estimations using the generalized method of moments (GMM). Two estimators are considered: the difference GMM (GMM diff), proposed by Arellano and Bond (1991), and the system GMM (GMM sys), developed by Blundell and Bond (1998). Given the balanced structure of the panel after data treatment and the absence of substantial gaps, the first-difference transformation was adopted to eliminate unobserved heterogeneity, making the use of forward orthogonal deviations unnecessary.

Following standard practice in dynamic panel data analysis, explanatory variables were classified according to their potential endogeneity based on economic reasoning and prior literature (Arellano & Bond, 1991; Blundell & Bond, 1998; Roodman, 2009). The dependent variable (DPCAR), along with OCR and NPL, was treated as endogenous, reflecting their contemporaneous interaction with banks' capital buffers (Berger & DeYoun, 1997; Shrieves & Dahl, 1992).

Balance-sheet and performance indicators (RORA, LIQ, LEV, and RAR) were considered predetermined, as they may respond to past shocks but are unlikely to be correlated with contemporaneous disturbances (Athanasoglou et al., 2008; Isayas, 2022). Bank size, although time-varying, was also treated as predetermined at the quarterly frequency. In contrast, INF, GDP, and the COVID dummy were assumed to be strictly exogenous, as they are determined outside individual banks' decision processes.

Table 6
Summary of explanatory variables used in the model

	Dimension	Variable	Formula
Internal variables	Asset quality	NPL	$\frac{Non-Performinf\ Loans}{Total\ Loans}$
	Management	OCR	$\frac{Costs\ and\ Operational\ Expenses}{Operational\ Revenues}$
	Earnings	RORA	$\frac{Net\ Profit}{Risk\ Weigthed\ Assets}$
	Liquidity	LIQ	$\frac{High\ Liquidity\ Assets}{Total\ Assets}$
		LEV	$\frac{Deposits}{Equity}$
	Sensitivity	RAR	$\frac{Market\ Risk\ Weigthed\ Assets}{Total\ Assets}$
	Bank size	SIZE	$LN(Assets)$
External variables	Economic growth	GDP	$\Delta\%\ GDP$
	Inflation	INF	$\Delta\%\ IPCA$
	COVID	COVID	Dummy = 1 from the second quarter of 2020 to the first quarter of 2021; otherwise, dummy = 0

Source: *Elaborated by the authors.*

To limit instrument proliferation, all GMM specifications employ a collapsed instrument matrix (Roodman, 2009), and the total number of instruments was kept at or below the number of cross-sectional units. Instrument validity is supported by standard overidentification tests and the absence of second-order serial correlation in the differenced residuals.

4. RESULTS

4.1 Descriptive Analysis

The first part of the results presents a descriptive analysis of the variables to identify relevant patterns among the financial and macroeconomic indicators considered in the study. Table 7 provides a statistical summary of the variables.

The dependent variable (DPCAR) exhibits a mean of 0.321 and moderate dispersion, with values ranging from negative observations to relatively high positive levels. This distribution indicates that, while most banks maintain capital buffers above regulatory requirements, some institutions experienced episodes of capital shortfall. Credit quality, measured by NPL, displays substantial heterogeneity across banks, reflecting differences in portfolio risk, whereas the OCR shows high dispersion and extreme values, suggesting heterogeneous managerial efficiency.

Risk-adjusted profitability indicators present relatively modest levels. RORA exhibits low dispersion, consistent with the constraints imposed by prudential regulation, while RAR shows greater variability, indicating heterogeneity in the composition of risk-weighted assets. LIQ and LEV also vary considerably, revealing distinct strategies across institutions. Macroeconomic variables (GDP and INF) display moderate volatility, consistent with relatively stable economic conditions over the sample period, yet with sufficient variation to affect banking performance.

Correlation analysis, as shown in Table 8, reveals strong associations between DPCAR and OCR, LIQ, LEV, and RAR, suggesting that higher capital buffers are associated with greater liquidity, higher leverage, stronger risk-adjusted profitability, and better cost structures. In contrast, correlations between DPCAR and GDP and INF are negative, indicating weaker prudential positions during periods of economic expansion.

Moreover, the absence of significant correlations between the COVID-19 dummy and CAMELS-related variables is consistent with BACEN (2022), reinforcing evidence of the resilience of the Brazilian banking system. Finally, variance inflation factors (VIFs) were calculated to assess multicollinearity. As all values were below 1.7, the results indicate that multicollinearity does not pose a concern, despite the presence of significant pairwise correlations.

4.2 Panel Regression Analysis

This section examines the panel regression models specified in Section 3.2. Table 9 reports the results from pooled, fixed-effects, random-effects and dynamic GMM estimations. The Lagrange multiplier and Hausman tests favor the fixed-effects specification, indicating the presence of unobserved heterogeneity correlated with the regressors.

Table 7
Descriptive statistical summary of quarterly variables for 2018-2024

Variable	Mean	Median	Minimum	Maximum	Standard deviation
DPCAR	0.3213	0.3175	-0.0814	0.7889	0.1261
NPL	0.0597	0.0524	0.0099	0.3260	0.0379
OCR	1.1658	1.0581	0.5660	8.6819	0.5790
RORA	0.0080	0.0071	-0.0122	0.0451	0.0058
LIQ	0.1513	0.1264	0.0080	0.5191	0.1015
LEV	11.2211	10.8314	2.4756	32.8324	5.0873
RAR	0.0226	0.0116	0.0001	0.2549	0.0386
SIZE	17.7990	17.2411	13.2842	21.7145	2.6258
GDP	0.0046	0.0045	-0.0264	0.0296	0.0087
INF	0.0131	0.0124	-0.0133	0.0317	0.0105

Source: *Elaborated by the authors.*

Table 8
Variable correlation chart

Panel A: correlation matrix											
	DPCAR	**NPL**	**OCR**	**RORA**	**LIQ**	**LEV**	**RAR**	**SIZE**	**GDP**	**INF**	**COVID**
DPCAR	1										
NLR	0.09*	1									
OCR	-0.30***	0.05	1								
RORA	0.05	-0.13***	-0.24***	1							
LIQ	0.21***	-0.18***	-0.18***	0.01	1						
LEV	-0.32***	0.22***	0.27***	-0.07	0.09*	1					
RAR	0.11**	0.25***	-0.10**	-0.09*	-0.13***	-0.31***	1				
SIZE	-0.12**	-0.13**	0.16***	0.06	0.00	0.43***	-0.34***	1			
GDP	-0.11**	0.18***	0.01	-0.02	-0.27***	0.06	-0.04	0.10**	1		
INF	-0.04	0.10**	0.10**	0.04	-0.09*	-0.03	0.03	0.01	-0.11**	1	
COVID	-0.02	-0.01	-0.01	-0.07	0.14**	0.01	0.02	-0.01	-0.49***	0.07	1
Panel B: VIF											
VIF	1.38	1.23	1.39	1.32	1.21	1.52	1.60	1.06	1.36	1.44	

VIF = variance inflation factor.
****, **, and * indicate respectively significance levels of 1%, 5%, and 10%,*
Source: *Elaborated by the authors.*

Table 9
Summary of panel models

	Pooled	**Fixed effect**	**Random effect**
NPL	-0.9847***	-0.1925	-0.1680
OCR	-0.0386***	-0.0146*	-0.0157**
RORA	-0.0303	2.9194***	2.9037***
LIQ	0.2911***	0.1747***	0.1708***
LEV	-0.0104***	-0.0067***	-0.0060***
RAR	-0.1421	-0.2280	-0.2152
SIZE	0.0061**	0.0153	-0.0011
GDP	-0.1177***	-0.1150***	-0.0486*
INF	-0.6414	-0.6455*	-0.4506
COVID	-0.0431**	-0.0323***	-0.0124
Intercept	0.4458***		0.4079***
R^2	0.2640	0.1860	0.1610
Adjusted R^2	0.2450	0.1340	0.1440
Model F statistic	14.068***	8.658***	76.0540***
F-test for fixed effects		51.784***	
Lagrange multiplier test		42.426***	
Hausman test		23.620***	
		Difference GMM	**System GMM**
NPL		-0.4767***	-0.7608**
OCR		-0.0193**	0.0389
RORA		0.9465*	6.3796***
LIQ		0.0809	0.6173**
LEV		-0.0163***	-0.0118
RAR		-0.9184***	0.4704

Table 9
Cont.

	Difference GMM	System GMM
SIZE	-0.1066*	0.0155**
GDP	0.0190	0.0554
INF	-0.3384	-0.1493
COVID	-0.0013	-0.0023
Instruments (n)	15	15
Wald test	359.5476***	522.6983***
AR(1)	-2.1999**	-1.8016*
AR(2)	-1.2409	-1.4711
Hansen difference test	-1.4211	

Note: *p-values for betas were calculated using the robust covariance matrix for panels.*
AR(1) = first-order autoregressive model; AR(2) = second-order autoregressive model; GMM = generalized method of moment.
****, **, and * indicate significance levels of 1%, 5%, and 10%, respectively.*
Source: *Elaborated by the authors.*

Given the dynamic nature of bank capital adjustment and potential endogeneity, the analysis also relies on dynamic panel estimators. The GMM diff results should be interpreted with caution, as the presence of second-order serial correlation in the differenced residuals suggests a violation of the moment conditions, limiting the reliability of this specification.

By contrast, the GMM sys estimator provides a more robust framework, with no evidence of second-order autocorrelation. In addition, Hansen's difference test supports the validity of the additional level instruments, indicating that they do not bias the estimates relative to the difference instruments. This result is particularly relevant in panels with small N and moderate T, where weak identification and instrument proliferation are key concerns.

Finally, the econometric analysis is not intended to maximize goodness of fit or predictive accuracy. Lower R^2 values in fixed-effects and dynamic models are expected due to the focus on within-bank variation. Accordingly, the primary objective is prudential inference rather than prediction, emphasizing economically and statistically meaningful relationships while properly addressing endogeneity and unobserved heterogeneity.

4.2.1 Asset quality

The NPL variable, associated with the CAMELS asset quality dimension, exhibits a negative and statistically significant coefficient in the pooled specification and, more importantly, in the dynamic GMM estimations. In particular, the GMM sys results indicate that banks with higher levels of non-performing loans tend to maintain smaller capital buffers above the regulatory minimum, reinforcing their characterization as riskier institutions from a prudential perspective.

Although the coefficient is not statistically significant in the fixed-effects model, the dynamic framework suggests that credit risk plays a relevant role in shaping capital buffers once endogeneity and adjustment dynamics are properly addressed.

From an economic perspective, higher credit risk exerts downward pressure on capital through increased loan-loss provisions and reduced profitability, limiting the resources available to build surplus capital. Moreover, a deterioration in asset quality increases risk-weighted assets, thereby raising the denominator of the CAR and further constraining capital adequacy.

These findings are consistent with prior empirical evidence reported by Abba et al. (2018) and Thach and Pham (2022), who also document a negative relationship between default risk and bank capitalization, highlighting the vulnerability of capital buffers to credit portfolio deterioration.

4.2.2 Management quality

The OCR displays a negative and statistically significant coefficient in the pooled and fixed-effects models, indicating that banks with higher operating costs relative to revenues tend to operate closer to the regulatory capital minimum. This result suggests that lower managerial efficiency is associated with smaller capital buffers.

Economically, a higher OCR reflects productivity losses, rigid cost structures, or compressed margins, which limit profit generation and slow equity accumulation. Since the CAR is sensitive to tier 1 capital, weaker management quality directly constrains banks' ability to sustain buffers above the regulatory minimum. This interpretation is consistent with the view that capital regulation exerts a disciplinary effect on managerial behavior, encouraging improvements in governance and operational efficiency (Lotto, 2018).

In the dynamic framework, the negative effect remains significant under GMM diff but loses significance and changes sign in the GMM sys specification. This pattern suggests that, once dynamic adjustment, unobserved heterogeneity, and simultaneity between management decisions and capitalization are fully controlled for, the independent effect of operating efficiency on capital buffers becomes less robust. Overall, the evidence indicates that managerial inefficiency is associated with lower capital buffers, although this relationship weakens in the fully specified dynamic model.

4.2.3 Earnings

In terms of profitability, corroborating previous literature, the calculated coefficients indicate a positive relationship between RORA and DCAR. Authors such as Abba et al. (2018) and Gharaibeh (2023), for example, highlight that profitability is a key determinant of bank solvency, reinforcing banks' ability to withstand shocks and comfortably meet regulatory capital requirements and, consequently, present a better prudential structure.

Furthermore, this analysis also reflects the potential endogeneity of CAMELS variables. Abreu and Camargos (2022), for example, analyzed how earnings are impacted by capital adequacy, reinforcing the need for appropriate models for analysis, such as GMM.

4.2.4 Liquidity

Concerning LIQ, it exhibits a positive relationship with DCAR in the pooled, fixed-effects, and GMM sys specifications, indicating that banks holding a higher share of liquid assets tend to maintain larger capital buffers above the regulatory minimum. This pattern reflects a more conservative balance-sheet structure and greater capacity to absorb adverse shocks, in line with the prudential literature linking liquidity to stronger capital positions and enhanced resilience (Bhattarai, 2020; Thach & Pham, 2022).

In contrast, the liquidity coefficient is not statistically significant in the GMM diff estimation, suggesting that short-term changes in liquid asset holdings do not exert a clear independent effect on DCAR once first differences are considered. This may reflect adjustment frictions, as liquidity rebalancing involves portfolio reallocations whose impact on capital buffers materializes over longer horizons. Accordingly, when level information and longer-run dynamics are incorporated in the GMM sys specification, the positive liquidity-capital relationship is restored.

As for LEV, a negative association with DCAR is observed across the traditional panel models and remains negative in the dynamic specifications. This result corroborates the findings of Aktas et al. (2015) and Thach and Pham (2022), indicating that more leveraged banks tend to operate with lower excess capital. Although leverage may enhance short-term returns, greater reliance on debt financing constrains the accumulation of capital buffers and reduces prudential resilience.

4.2.5 Sensitivity

Finally, the CAMELS risk sensitivity dimension presents mixed results across specifications. The traditional panel models indicate a negative relationship between market risk exposure and DPCAR, suggesting that banks with higher sensitivity to market risk tend to operate with smaller capital buffers, possibly reflecting more aggressive risk-taking behavior, in line with Hunjra et al. (2020), Keqa (2021), and Lappay et al. (2021).

By contrast, the GMM sys results reveal a positive association between market risk sensitivity and DPCAR, in line with Abba et al. (2018). This finding suggests that, once endogeneity and dynamic adjustment are properly accounted for, banks with higher market risk exposure tend to maintain larger levels of capital buffers, either in response to regulatory requirements or because better-capitalized institutions are more capable of absorbing market fluctuations. Overall, the evidence indicates that the relationship between market risk sensitivity and capital buffers is specification-dependent, with dynamic estimates highlighting the compensatory role of capital in managing market risk.

4.2.6 Size

Bank size, measured as the natural logarithm of total assets, exhibits a specification-dependent relationship with DPCAR. In the GMM diff estimation, size is negatively associated with capital buffers, indicating that larger banks tend to operate closer to the regulatory minimum. This pattern may reflect diversification benefits, economies of scale, and more stable funding structures, allowing large institutions to sustain thinner buffers without compromising prudential soundness. Similar results are reported in emerging market studies by Bhattarai (2020), Thach and Pham (2022), and Thuong et al. (2024).

By contrast, the GMM sys results reveal a positive and statistically significant coefficient for bank size, suggesting that once long-run dynamics, unobserved heterogeneity, and endogeneity are properly controlled for, larger banks tend to maintain higher capital buffers. From a prudential perspective, this finding may reflect stricter regulatory scrutiny of systemically important institutions, as well as their greater capacity to generate internal capital and access capital markets. This interpretation is consistent with evidence reported by Aktas et al. (2015) and Keqa (2021).

4.2.7 External variables

Regarding macroeconomic factors, traditional panel estimations reveal a negative relationship between DCAR and GDP, consistent with the procyclical nature of banking behavior. During economic expansions, higher risk appetite and credit growth tend to lead banks to operate with thinner capital buffers, as resources are allocated to balance-sheet expansion rather than prudential accumulation.

In the dynamic framework, however, the effect of GDP on DCAR loses statistical significance once endogeneity and adjustment dynamics are explicitly controlled for. This suggests that economic growth affects capital buffers mainly through indirect channels, such as profitability, credit risk, or balance-sheet composition, rather than through a direct impact on excess capital, in line with Nguyen (2023).

Inflation exhibits a negative and statistically significant effect on DCAR in the fixed-effects and GMM sys models, indicating that rising prices weaken banks' capacity to sustain higher capital adequacy levels. Higher inflation increases operating and funding costs, compresses margins, and is often associated with tighter monetary conditions, thereby constraining internal capital generation. This evidence corroborates the findings of Bhattarai (2020), Thach and Pham (2022), and Thuong et al. (2024).

Finally, the COVID dummy controls for an exogenous systemic shock that altered macroeconomic conditions and the prudential environment. Although not statistically significant in the dynamic specifications, its inclusion isolates the effects of pandemic-related uncertainty and temporary regulatory flexibility, ensuring that the estimated relationships for GDP and inflation are not confounded by this extraordinary episode.

4.2.8 Robustness and key determinants

The empirical analysis identifies key determinants of the additional capital held by banks above the regulatory minimum, as measured by DCAR. Overall, the results are consistent with theoretical expectations and prior empirical evidence, although some relationships exhibit sensitivity to the econometric specification. A central finding is the presence of endogeneity among key explanatory variables – particularly profitability, liquidity, and leverage – highlighting the importance of dynamic estimators capable of addressing simultaneity and capital adjustment processes.

Comparisons between traditional panel models and dynamic specifications show that, once endogeneity is properly controlled for, some relationships lose statistical significance or become specification-dependent, as observed for GDP and liquidity. This outcome underscores the complexity of interactions between bank-specific factors and macroeconomic conditions, as well as the limitations of static approaches in capturing these dynamics.

Despite this sensitivity, four variables remain robust across specifications in both sign and statistical significance: non-performing loans, RORA, leverage, and inflation. The stability of these effects indicates that asset quality, profit-generating capacity, financial structure, and the inflationary environment are central determinants of banks' prudential behavior and their ability to sustain capital buffers above the regulatory minimum.

Taken together, these findings suggest that policymakers and bank managers should closely monitor these dimensions, particularly during periods of financial stress or economic expansion. Moreover, the comparison between static and dynamic models reinforces the relevance of endogeneity among CAMELS indicators and supports the GMM sys results – validated by standard diagnostic tests – as providing the most reliable basis for prudential inference.

5. FINAL CONSIDERATIONS

This study examined the main determinants of capital adequacy in Brazilian commercial banks under the Basel III framework, with emphasis on CAMELS dimensions and macroeconomic conditions. Bank capitalization plays a central role in financial stability amid increasing regulatory complexity and systemic risk, making the identification of the drivers of capital buffers essential for both regulatory design and banks' strategic decisions.

The empirical analysis used quarterly panel data from 15 Brazilian commercial banks from 2018 to 2024. Static panel models were initially estimated, followed by dynamic specifications using GMM diff and GMM sys estimators to address endogeneity, simultaneity, and capital adjustment dynamics. The dependent variable, defined as the difference between observed capital adequacy and the regulatory minimum, provided a direct measure of prudential capital buffers.

The results indicate that capital buffers are determined by a combination of bank-specific characteristics and macroeconomic conditions, although their effects depend on the econometric specification. Asset quality, profitability, leverage, and inflation emerge as the most robust determinants, consistently influencing capital buffers across models. Banks with higher credit quality, stronger profit-generating capacity, lower leverage, and operating in lower-inflation environments tend to hold higher levels of capital above the regulatory minimum.

Other CAMELS dimensions and control variables, including management efficiency, liquidity, market risk sensitivity, bank size, and economic growth, show greater sensitivity to model specification. While static models yield intuitive relationships, these effects often weaken once endogeneity and dynamic adjustment are accounted for, underscoring the relevance of dynamic panel approaches for prudential analysis.

Despite its contributions, this study has limitations. The relatively small sample of banks may restrict external validity, and institutional or governance variables were not explicitly incorporated. Future research could expand the sample, include qualitative indicators of governance and risk management, and explore structural models to better identify indirect transmission channels, particularly those linking macroeconomic conditions to capital buffers.

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DATA AVAILABILITY STATEMENT

The entire dataset supporting the results of this study is available at https://www3.bcb.gov.br/ifdata/

The entire dataset supporting the results of this study can be made available upon request to the authors.

GENERATIVE AI DISCLOSURE

The authors declare that generative artificial intelligence was used in the following stages of the production of this manuscript:

- Text refinement: ChatGPT.

The author(s) declare(s) that, regardless of the use of the tools mentioned above, all generated content was supervised, verified, and critically validated by humans. The author(s) assume(s) full and exclusive responsibility for the accuracy of the data, integrity of mathematical/statistical formulas, originality of the text, and the conclusions presented in the published article.