Green rules, safer banks? ESG and bank risk in Brazil

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Abstract The increasing integration of Environmental, Social, and Governance (ESG) principles into banking supervision has reshaped financial regulation and risk assessment. We study the impact of the National Monetary Council's (CMN) Resolutions 4,327/2014 and 4,945/2021 on bank risk in Brazil. These regulations represent a critical evolution in the regulatory landscape of sustainable banking. Employing a difference-in-differences (DiD) design, we assess how these regulatory interventions influenced the relationship between ESG scores and bank risk. We find that Resolution 4,327/2014 led to a significant reduction in bank risk among initially low-ESG banks, reflected in improvements in subsequent capital adequacy and asset risk. In contrast, the marginal impact of Resolution 4,945/2021 is weaker, suggesting diminishing effects once banks have internalized ESG regulations. Our study contributes to the literature on ESG regulation, bank risk, and emerging markets.

Keywords: ESG regulation; Bank risk; Sustainable finance; Difference-in-Differences.

JEL codes: G21, Q51, E58, G38.

1. Introduction

Environmental, social, and governance (ESG) risks have become increasingly central to financial stability, particularly in banking systems exposed to climate transition risks, environmental degradation, and governance failures.

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In response, regulators worldwide have moved beyond voluntary frameworks toward mandatory ESG supervision, positioning ESG regulation as a macroprudential tool rather than a purely ethical or reputational concern. Despite this shift, empirical evidence on whether ESG regulation actually reduces bank risk, especially in emerging markets, remains limited.

Brazil offers a particularly informative context to examine these issues. The country's financial system is bank-based and concentrated, granting large commercial banks substantial influence over the allocation of credit across sectors of the economy. At the same time, Brazil is especially exposed to environmental and climate-related risks, including deforestation, biodiversity loss, and climate transition pressures that can translate into material financial risks for lenders (Berger et al., 2026). Existing research indicates that when environmental regulation is weakly enforced, financial institutions may continue to supply credit to environmentally harmful activities, thereby embedding latent environmental and transition risks into bank balance sheets and increasing long-term financial vulnerability (Kedward et al., 2023; Feng et al., 2023). This interaction between regulatory gaps and bank lending behavior highlights the importance of assessing whether binding ESG regulation, rather than voluntary or market-driven ESG adoption, constrains bank risk-taking and alters credit allocation in ways that mitigate systemic environmental and financial risks (Kirschenmann, 2022).

This paper focuses on two major regulatory interventions introduced by the National Monetary Council (CMN), Resolutions 4,327/2014 and 4,945/2021, which established mandatory frameworks for socio-environmental and climate-risk management. Together, these resolutions represent a staged regulatory approach: an initial rule that imposed substantive behavioral requirements, followed by a later reform that reinforced transparency and supervisory consistency.

Resolution 4,327/2014 was the first to require financial institutions to adopt a Social and Environmental Responsibility Policy (PRSA), obliging banks to identify, evaluate, and mitigate social and environmental risks associated with their lending portfolios. Later, Resolution 4,945/2021 expanded these

obligations by explicitly incorporating climate-related financial risks and strengthening requirements for governance, disclosure, and transparency. These resolutions represent a progressive regulatory trajectory to align the financial system with Brazil's sustainability goals.

We focus on whether these two regulatory milestones altered the relationship between banks' ESG performance and their risk profiles. We argue that these two regulatory interventions should have asymmetric effects on bank risk. The introduction of Resolution 4,327/2014 constituted a binding supervisory shock, particularly for banks with weak pre-existing ESG practices. By forcing these institutions to internalize social and environmental risks, the regulation likely improved risk governance, asset quality, and capital buffers. In contrast, Resolution 4,945/2021 primarily strengthened disclosure and climate-risk integration in a system where ESG frameworks were already largely in place, suggesting diminishing potential marginal effects on banks' risk profiles.

We employ a difference-in-differences (DiD) design. Banks are classified into treated (low-ESG performance) and control (high-ESG performance) groups based on their ESG scores from the pre-regulation period. The identifying assumption is that the regulatory change affects banks in different ways, depending on their pre-regulation level of ESG performance. We expect the change to be more binding for low-ESG banks as these banks must improve, while it should not be binding (or less binding) for high-ESG banks as they comply already with the new requirements. Hence, low-ESG banks are more likely to respond to the regulatory change. This design isolates the causal impact of ESG regulation by comparing changes in risk outcomes across banks with heterogeneous predetermined exposure to regulatory tightening, consistent with recent studies on mandatory ESG disclosure and green credit policies (e.g., Chiaramonte et al., 2022; Danisman and Tarazi, 2024; Ho and Wong, 2023; Zhang et al., 2023; Krueger et al., 2024; Zhao and Zhu, 2024; Bischof et al., 2025; Green and Vallee, 2025).

Our analysis shows a clear contrast between the two regulatory interventions in terms of risk convergence. Following the introduction of Resolution 4,327/2014, we find clear evidence that the risk gap between banks with low

and high pre-regulation ESG performance narrows substantially, with low-ESG banks adjusting more strongly along multiple risk dimensions. Additional analyses further reveal that these effects are driven primarily by the social and governance pillars, whereas the environmental dimension does not exhibit statistically significant effects, suggesting that the early implementation of Brazil's ESG banking framework extended beyond environmental considerations alone. In contrast, Resolution 4,945/2021 does not generate additional convergence in bank risk. By the time of its implementation, ESG governance and risk management practices appear to have been largely institutionalized, leaving limited scope for further compression in risk heterogeneity. Together, these findings suggest that ESG regulation can act as a convergence mechanism when it represents a binding shock, but that subsequent regulatory refinements primarily consolidate existing practices rather than inducing additional risk adjustments.

Our analysis departs from the existing literature in several ways. First, rather than examining the correlation between ESG scores and bank risk, we focus on regulation as the treatment, thereby distinguishing regulatory effects from voluntary ESG engagement. Second, by studying two sequential regulatory reforms, we assess how sequencing in regulatory agendas shapes marginal financial outcomes. Third, by focusing on Brazil, we provide evidence from a major emerging market where ESG regulation, enforcement capacity, and environmental exposure have become increasingly important.

Our analysis contributes to three strands of literature. It complements studies on ESG disclosure by examining real risk outcomes rather than capital market reactions. We also add to the banking literature by showing how ESG supervision and regulation operate as an external governance mechanism. Finally, our study informs policy debates on sustainable finance by demonstrating that the effectiveness of ESG regulation depends on timing, scope, and initial institutional conditions (Chen and Xie, 2022; Tsang et al., 2024; Filgueira and Norden, 2025; Zhou and Feng, 2025).

The remainder of the paper is organized as follows. In Section 2, we discuss the related literature and develop a set of hypotheses. In Section 3, we describe

the data and empirical strategy. In Section 4, we present the results and discuss their implications. Section 5 concludes.

2. Literature and hypotheses

2.1 ESG regulation and financial stability

A growing body of research shows that ESG considerations are increasingly relevant for financial stability, particularly through their interaction with information asymmetry, governance, and risk management. Early studies focused on voluntary ESG adoption, while recent work emphasizes the central role of mandatory ESG regulation and disclosure in shaping firm behavior and financial outcomes. Dikau and Volz (2021) argue that central banks and regulators should integrate sustainability objectives into their mandates, as climate-related risks directly affect macro-financial stability. The study suggests that without a regulatory framework aligned with ESG goals, banks may underinvest in sustainability, increasing systemic risk. Zhou et al. (2022) similarly highlight the role of government mandates in enabling effective ESG implementation.

Cross-country evidence indicates that mandatory ESG disclosure improves information environments by enhancing transparency, price discovery, and market liquidity, especially for firms with weak pre-regulation disclosure incentives (Zhang et al., 2023; Krueger et al., 2024). These effects are stronger when disclosure mandates are implemented by government authorities and supported by credible enforcement. Improved information environments, in turn, reduce uncertainty and facilitate monitoring by investors, creditors, and supervisors.

In the banking sector, ESG regulation is particularly consequential because environmental and social risks can translate directly into credit risk, asset quality deterioration, and pressure on capital adequacy (Roncoroni et al., 2021; Giannetti et al., 2024; Kim et al., 2025). Studies on European banks show that institutions with stronger ESG strategies are more resilient during periods of financial stress, but that these benefits are closely tied to regulatory and

supervisory frameworks rather than voluntary ESG engagement (Chiaramonte et al., 2022). Similarly, climate stress tests and supervisory disclosure requirements improve risk awareness and induce portfolio adjustments, although their effects are uneven and depend on banks' initial ESG exposure and preparedness (Bischof et al., 2025).

Prior research documents a general negative relationship between ESG performance and bank risk, suggesting that higher ESG scores enhance stability by promoting better governance, social engagement, and environmental management (Danisman and Tarazi, 2024; Curcio et al., 2024). However, findings remain mixed, as some studies observe risk-increasing effects of ESG engagement due to overinvestment or reputational exposure (Bruno et al., 2024; Del Sarto, 2025).

The effectiveness of ESG regulation is likely to be particularly salient in emerging markets, where voluntary ESG adoption is uneven and enforcement capacity varies. Evidence from China's Green Credit Policy shows that regulatory mandates can reduce bank credit risk, but primarily for institutions with sufficient scale and expertise to implement new standards (Zhou et al., 2022). Gangwani and Kashiramka (2024) study commercial banks in emerging market economies and find that banks with higher ESG disclosure scores have a reduced bank risk and an increased bank value. This highlights the importance of heterogeneous treatment effects, with regulation having the strongest impact on those institutions that initially lag behind best practice.

In Brazil, the Central Bank of Brazil's (BCB) regulatory agenda mirrors this global trend. Resolution 4,327/2014 established an institutional foundation for ESG integration, while Resolution 4,945/2021 extended this framework, emphasizing the materiality of environmental and governance disclosures. Related research suggests that such regulatory environments reduce moral hazard, strengthen risk management, and lower credit and liquidity risks (Chiaramonte et al., 2022; Liu and Xie, 2024). Market-level studies in Brazil indicate that higher ESG scores are associated with lower volatility and lower cost of capital, but not necessarily higher returns (Farias and Almeida, 2024; Possebon et al., 2024). This pattern is in line with the interpretation of ESG

being a risk-mitigation strategy rather than a performance-enhancing strategy. However, recent evidence also shows that weak enforcement of environmental regulation can lead banks to expand lending to environmentally harmful activities, suggesting that ESG rules without credible supervision may fail to improve risk outcomes (Berger et al., 2026).

Moreover, greenwashing and weak enforcement have diluted ESG credibility in Brazil (De Alencar Caldas et al., 2021). This highlights the importance of regulatory frameworks to ensure the authenticity and consistency of ESG practices. These resolutions aim to reduce such inconsistencies, making them an ideal case for examining regulatory-induced changes in ESG-risk dynamics in the banking sector.

2.2 Hypotheses

The introduction of Resolution 4,327/2014 represented a substantive regulatory shift by mandating the formal integration of social and environmental risks into banks' governance, credit assessment, and internal control frameworks. For banks with weak pre-regulation ESG performance, this regulation constituted a binding shock, requiring significant adjustments in risk management practices. Low-ESG banks, which had previously underweighted ESG-related risks, were forced to strengthen screening standards, improve governance structures, and internalize risks that had been largely externalized. As a result, these banks are expected to reduce overall risk exposure through higher capital buffers, lower leverage, and safer asset allocation. Based on this reasoning, we expect that Resolution 4,327/2014 caused a significant decline in bank risk among low-ESG banks. Therefore, we state Hypothesis 1 as follows:

Hypothesis 1: *Low-ESG banks show a significant decline in bank risk following Resolution 4,327/2014.*

Resolution 4,945/2021 expanded the existing regulatory framework by incorporating climate-related financial risks and enhancing disclosure and supervisory alignment. However, unlike the 2014 resolution, this regulation was introduced in a context where ESG governance structures had already been widely adopted and institutionalized across the banking sector. At this stage,

most banks, particularly those with initially low-ESG performance, had already adjusted their risk management practices in response to earlier regulatory pressure and market discipline. Consequently, the 2021 reform is expected to generate limited additional change, functioning primarily as a refinement and standardization of existing practices rather than a new binding constraint. This regulatory sequencing implies diminishing marginal effects on bank risk following Resolution 4,945/2021. Therefore, we state Hypothesis 2 as follows:

Hypothesis 2: *The marginal impact of Resolution 4,945/2021 on bank risk is weaker, as most banks have already internalized the required ESG practices.*

If ESG regulation disproportionately affects banks with weak pre-regulation ESG performance, it should also operate as a convergence mechanism that reduces heterogeneity in bank risk. Low-ESG banks face stronger incentives to adjust following regulatory intervention, while high-ESG banks—already closer to regulatory benchmarks—exhibit more limited scope for further improvement. Over time, this asymmetric adjustment leads to a narrowing of the risk differential between the two groups. Such convergence may arise through multiple channels, including stronger capital accumulation and portfolio risk reduction among low-ESG banks, as well as stabilization in asset quality across institutions. Therefore, following the issuance of each regulatory intervention, the gap in risk between low-ESG and high-ESG banks is expected to decrease, reflecting reduced dispersion in bank risk rather than uniform changes in risk levels. We state Hypothesis 3 as follows:

Hypothesis 3: *The gap in risk between low-ESG and high-ESG banks narrows after each regulatory resolution.*

3. Data and empirical strategy

3.1 Data

Our sample comprises 17 publicly listed Brazilian banks that have ESG scores available during the period 2010–2024, which account for approximately 60% of the total assets of the Brazilian banking sector in 2024. We obtain bank-level ESG data from London Stock Exchange Group (LSEG) Data & Analytics,

formerly Refinitiv. Specifically, we collect information on the overall ESG score and its three constituent pillars (Environmental, Social, and Governance). In addition, we collect bank-level balance sheet and income statement data from LSEG Data & Analytics. To ensure data reliability, we cross-check the extracted financial information with publicly available COSIF database (Plano Contábil das Instituições do Sistema Financeiro Nacional) maintained by the BCB.

The ESG score measures a firm's environmental, social, and governance performance using more than 870 underlying indicators. From this universe, a subset of 186 industry-specific material indicators is selected to compute the scores. These indicators are grouped into ten categories, which are subsequently aggregated into the three pillar scores and, ultimately, into the overall ESG score. The resulting measure reflects a firm's ESG performance, commitment, and effectiveness based on publicly disclosed information.

The three ESG pillars capture distinct dimensions of corporate sustainability. The Environmental score assesses how effectively a firm manages resource use, emissions, and environmental innovation. The Social score evaluates workforce practices, human rights, community engagement, and product responsibility. The Governance score reflects the quality of corporate governance structures, including management practices, shareholder rights, and corporate social responsibility (CSR) strategy.

Because bank risk is inherently multidimensional and cannot be fully captured by a single indicator, we employ several risk proxies in our analysis. These proxies capture key aspects of bank risk and are routinely used by bank supervisors and regulators, including capital adequacy and solvency (CAP), asset risk (RWA), credit risk (NPL_ratio), and leverage or financial structure (Leverage). Table 1 provides detailed definitions of all variables and summary statistics.

3.2 Empirical strategy and identification

In our analysis, we employ a DiD design to identify the causal impact of ESG regulatory changes on bank risk. We classify banks with ESG scores

Table 1
Summary statistics

Variable	Variable description	Mean	SD	Min	Max	Count
Dependent variables						
CAP	Capital Adequacy Ratio = (Tier 1 Capital + Tier 2 Capital) / Risk-Weighted Asset	0.163	0.052	0.085	0.537	157
RWA	Risk-Weighted Asset / Total Assets	0.667	0.219	0.057	1.565	193
NPL_ratio	Non-Performing Loans / Total Loans	0.020	0.018	0.000	0.076	102
Leverage	Debt / Equity	3.221	2.238	0.005	17.020	241
Independent variables						
ESG	ESG Score	63.084	24.389	6.924	92.707	89
E score	Individual Environmental Score	70.051	28.400	2.196	96.313	89
S score	Individual Social Score	70.487	23.384	8.129	95.349	89
G score	Individual Governance Score	53.139	29.599	2.828	95.477	89
Control variables						
Size	Natural logarithm of Total Assets	24.837	1.941	20.068	28.680	242
EBIT_TA	Earnings Before Interest and Taxes / Total Assets	0.022	0.027	−0.050	0.240	235
RE_TA	Retained Earnings / Total Assets	0.031	0.021	−0.036	0.094	241

below the median ESG in the pre-period as treated group and those with ESG scores above the median in the pre-period as control group. The first regulatory change occurs in 2014 (Resolution 4,327), and the second in 2021 (Resolution 4,945). In order to analyze the impact of Resolution 4,327, we calculate the median for all banks between 2010 and 2014. We consider a bank as treated if their average ESG score in the years between 2010 and 2014 is below the median ESG score of all banks in the same period. We repeat this classification for the E, S and G scores. To analyze the impact of Resolution 4,945, we follow the same procedure, considering the median for all banks between 2010 and 2021 as benchmark.

We estimate the following DiD model with bank controls, bank fixed effects, and time fixed effects:

$$\begin{aligned} \textit{Bank risk}_{i,t} = \alpha + \beta_1 \textit{Resolution}_t \times \textit{Treated}_i \\ + \textit{Bank controls}_{i,t-1} + \gamma_i + \theta_t + \varepsilon_{i,t}, \end{aligned} \tag{1}$$

where $\textit{Resolution}_t$ is a binary variable equal to one after the implementation of each resolution, and zero otherwise. $\textit{Treated}_i$ is equal to one for banks below the median ESG score in the pre-period, and zero otherwise. The single term *Resolution* is absorbed by the time fixed effects θ_t and the single term *Treated* is absorbed by the bank fixed effects γ_i.

Before the introduction of each regulation, risk indicators for low-ESG and high-ESG banks follow closely aligned trajectories, with no systematic evidence of convergence or divergence. This similarity in pre-treatment dynamics is in line with the parallel trend assumption required for a DiD analysis and strengthens the causal interpretation of the estimated regulatory effects.

4. Empirical results

4.1 Main effects of ESG regulation on bank risk

Table 2 presents the results from our DiD regressions, assessing whether and how the implementation of the Resolution 4,327/2014 influenced bank risk

in Brazil. The coefficients on $Resolution_t \times Treated_i$ capture how risk changed for low-ESG banks (treated) relative to high-ESG banks (control) after this regulatory change.

Consistent with our expectation, the results indicate that treated (low-ESG) banks significantly reduce their risk after the Resolution 4,327/2014. Following the issuance of this regulation, treated banks display improvements in capital adequacy ratios and reductions in risk-weighted assets relative to the control group. This finding supports the view that the mandatory adoption of PRSA under Resolution 4,327/2014 incentivized previously underperforming banks to improve internal risk management frameworks and ESG governance structures.

This result aligns with global evidence showing that tighter ESG standards can improve financial resilience, such as the positive impact of China's Green Credit Policy on credit risk reduction in state-owned banks (Zhou et al., 2022) and the stabilizing effects of mandatory ESG disclosure frameworks in the European Union (Krueger et al., 2024).

4.2 Marginal effects after Resolution 4,945/2021

Table 3 presents the corresponding DiD results for Resolution 4,945/2021. The interaction term for this second main regulatory intervention shows a risk reduction, but it is not statistically significant in most specifications. This finding is consistent with our Hypothesis 2, suggesting that by 2021 low-ESG banks had already converged toward higher ESG standards, leaving limited scope for further risk reductions.

Resolution 4,945/2021 focuses on integrating climate-related financial risks, improving disclosure quality, and strengthening governance mechanisms, rather than introducing new risk-based incentives. Consequently, the regulatory change likely enhances transparency rather than altering underlying bank risk. This attenuation is consistent with findings from other regulatory contexts, such as the post-Paris Agreement period, when most financial institutions had already (somehow) internalized ESG risk practices, leading to smaller marginal effects of more recent regulations (Cucinelli et al., 2026).

Table 2
The impact of Resolution 4,327/2014 on bank risk

Variables	(1) CAP	(2) RWA	(3) NPL_ratio	(4) Leverage
Res4327×Treated	0.028***	−0.060**	0.001	−0.540
	(0.007)	(0.024)	(0.005)	(0.765)
Controls				
Size	−0.051***	−0.112*	−0.009	4.064***
	(0.012)	(0.057)	(0.008)	(0.663)
EBIT_TA	0.545***	0.776	−0.142	−14.857
	(0.135)	(0.815)	(0.091)	(9.922)
RE_TA	0.147	1.369	0.030	5.229
	(0.150)	(1.901)	(0.114)	(8.248)
Bank FE	YES	YES	YES	YES
Time FE	YES	YES	YES	YES
Number of observations	154	190	101	234
R^2	0.872	0.824	0.890	0.681

Note. This table shows the estimation results of Equation (1). Robust standard errors are clustered at the bank level and shown in parentheses. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Table 3
The impact of Resolution 4,945/2021 on bank risk

Variables	(1) CAP	(2) RWA	(3) NPL_ratio	(4) Leverage
Res4945×Treated	0.014	−0.044	0.001	−0.389
	(0.014)	(0.059)	(0.004)	(0.451)
Controls				
Size	−0.054***	−0.106*	−0.009	4.086***
	(0.010)	(0.056)	(0.007)	(0.668)
EBIT_TA	0.496***	0.924	−0.143	−14.091
	(0.137)	(0.851)	(0.088)	(9.911)
RE_TA	0.149	1.301	0.028	4.626
	(0.143)	(1.834)	(0.109)	(8.150)
Bank FE	YES	YES	YES	YES
Time FE	YES	YES	YES	YES
Number of observations	154	190	101	234
R^2	0.868	0.824	0.890	0.680

Note. This table shows the estimation results of Equation (1). Robust standard errors are clustered at the bank level and shown in parentheses. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

4.3 Risk convergence following Resolution 4,327/2014 and Resolution 4,945/2021

Figure 1 presents event-time plots comparing the evolution of bank risk for low-ESG (treated) and high-ESG (control) banks around the introduction of Resolution 4,327/2014. Across all measures, trends are broadly parallel prior to regulation, supporting our identification strategy and indicating no pre-existing convergence between the groups.

Following the regulatory change, clear evidence of risk convergence emerges. Capital adequacy ratios increase more strongly among low-ESG banks, leading to a rapid narrowing (and partial reversal) of the pre-regulation gap relative to high-ESG banks. Similarly, leverage declines sharply for low-ESG banks after 2014, while high-ESG banks experience rising leverage, resulting in a pronounced reduction of balance-sheet risk differentials.

Convergence is also evident in portfolio risk. Risk-weighted assets decline more substantially for low-ESG banks following regulation, reflecting a shift towards less risky asset allocations and a significant reduction in the risk gap relative to high-ESG banks. Finally, asset quality convergence is observed in realized credit risk outcomes. While high-ESG banks exhibit higher non-performing loan ratios prior to 2014, these ratios decline markedly after regulation, whereas NPLs for low-ESG banks remain low and stable, leading to a substantial narrowing of the asset quality gap.

Taken together, the evidence across all four risk proxies indicates that Resolution 4,327/2014 reduced heterogeneity in bank risk by inducing stronger adjustments by banks with weaker pre-regulation ESG performance and facilitating catch-up in asset quality with their high-ESG peers. This pattern is consistent with our Hypothesis 3 and supports the interpretation of ESG regulation as a convergence mechanism that reduces heterogeneity in bank risk rather than uniformly shifting risk levels across institutions.

Figure 2 presents the corresponding event-time plots comparing the evolution of bank risk for the treated (low-ESG) and control (high-ESG) banks around the introduction of Resolution 4,945/2021. The evidence indicates that

Resolution 4,945/2021 did not generate additional convergence in bank risk between low-ESG and high-ESG banks. Except for Leverage, across three risk proxies, post-2021 dynamics are characterized by parallel movements rather than differential adjustment. This contrasts sharply with the clear convergence observed following the earlier Resolution 4,327/2014.

These findings are in line with our Hypothesis 3 when interpreted in a sequential regulatory framework. The earlier regulation acted as a binding regulatory shock that reduced risk heterogeneity across banks. At the time the Resolution 4,945/2021 was introduced, ESG governance and risk management practices have already been largely internalized, leaving limited scope for further convergence. As a result, the 2021 reform appears to have primarily reinforced disclosure and supervisory alignment rather than affecting banks' underlying risk profiles.

4.4 Dynamic effects

To further explore the dynamics of the regulatory impact, we estimate an event-study specification by interacting the treatment indicator with year dummies surrounding each resolution. To illustrate the results, we plot the yearly coefficients in Figure 3.

The event study analysis shows heterogeneous responses across regulatory interventions affecting low-ESG banks, as shown in Panel A. Following Resolution 4,327/2014, capital ratios increase gradually and persistently, with no evidence of differential pre-treatment trends, indicating a delayed but durable adjustment in long-run bank behavior. In contrast, the response to Resolution 4,945/2021 is characterized by a discrete level shift rather than a gradual dynamic pattern. Coefficients remain close to zero throughout the pre-treatment period (2012–2019), while capital ratios become positive and remain consistently above zero from 2020 onward, prior to the resolution. This pattern suggests an anticipation prior to the late resolution.

Event study evidence indicates distinct balance-sheet adjustment patterns across regulatory interventions affecting low-ESG banks, as shown in Panel B. For Resolution 4,327/2014, risk-weighted assets display stable pre-treatment

dynamics and shift further downward following the 2014 issuance, remaining persistently more negative thereafter, consistent with a gradual and durable reduction in risk exposure. In contrast, RWA coefficients associated with Resolution 4,945/2021 are highly stable throughout the pre-treatment period from 2011 to 2019, providing strong support for the parallel trend assumption. Beginning in 2020, coefficients decline further, suggesting anticipatory balance-sheet adjustments prior to formal issuance in 2021. Focusing on the post-implementation period, RWA remains persistently lower from 2022 onward.

Event study estimates of the non-performing loan (NPL) ratio for low-ESG banks display positive but small coefficients throughout the sample period, as shown in Panel C. Pre-treatment estimates are stable and show no evidence of differential trends, supporting the validity of the event study design. Following the issuance of Resolution 4,327 in 2014, NPL ratio point estimates increase modestly but remain statistically indistinguishable from zero, as confidence intervals consistently include the zero line. A similar pattern is observed for Resolution 4,945/2021: while coefficients are slightly positive after 2021, post-treatment estimates from 2022 onward are not statistically significant. Overall, the results indicate that neither resolution had a robust effect on non-performing loans, suggesting that the regulatory interventions did not materially alter credit quality for low-ESG banks.

Event study estimates of leverage for low-ESG banks show mainly positive coefficients throughout the sample period, as shown in Panel D. Following the issuance of Resolution 4,327 in 2014, leverage point estimates remain modestly positive but are not statistically distinguishable from zero, as confidence intervals consistently include the zero line. A similar pattern emerges for Resolution 4,945. Overall, the results indicate that neither resolution had a meaningful impact on leverage, suggesting that banks adjusted along alternative margins rather than through changes in capital structure.

4.5 Further analyses

We perform several additional analyses and robustness tests that we briefly summarize in the remainder.

First, to further explore the channels through which ESG performance interacts with prudential regulation, Tables 4 and 5 decompose the overall ESG score into the E, S, and G scores. We examine the impact of banks' individual E, S, and G scores in the pre-period on bank risk after the Resolutions 4,327/2014 and 4,945/2021. We now replace the variable *Treated* by the indicators *Treated_E*, *Treated_S*, and *Treated_G* (that equal one if a bank has a below median average E, S, or G score in the pre-period, respectively), and interact them with indicators for the two regulatory resolutions. Table 4 reveals important heterogeneity across the ESG dimensions. While the Social and Governance pillars exhibit significant effects on bank capitalization following Resolution 4,327/2014, the Environmental pillar does not produce statistically significant effects across the baseline risk measures. This finding suggests that the overall ESG results are primarily driven by the social and governance dimensions. Although this may appear counterintuitive given the growing emphasis on environmental issues in sustainable finance, it is consistent with the institutional design of Resolution 4,327/2014, which established a broader PRSA emphasizing governance, internal processes, and the management of both social and environmental risks, rather than climate-related issues alone.

Table 5 repeats the analysis for Resolution 4,945/2021. In this case, the results in most of the models are not statistically significant. However, one exception is Table 5, Panel A, showing a statistically significant positive treatment effect of the Environmental score on the non-performing loans ratio (NPL_ratio), pointing to an increase in credit risk for banks with a low E-score in the pre-period. This finding suggests that, in the post-2021 regulatory context, environmental initiatives may be linked to transitional or adjustment costs that temporarily increase credit risk, while no robust evidence emerges for a stabilizing role of the Social or Governance dimensions.

Second, to assess whether the baseline results are driven by the contemporaneous implementation of Basel III, we split the sample according to banks' initial capital buffers, measured as the difference between the capital ratio and the 8% regulatory minimum. If Basel III was the primary driver of our findings, stronger treatment effects would be expected among banks with low

Figure 1
Parallel trends - effect of Resolution 4,327/2014



This figure illustrates the behavior of the average Score, before and after the Resolution 4,327/2014 for both treated and control group.

Table 4
The impact of Resolution 4,327/2014 on bank risk by E, S, and G scores
Panel A: E score

Variables	(1) CAP	(2) RWA	(3) NPL_ratio	(4) Leverage
Res4327×Treated_E	−0.006	−0.023	−0.004	−0.535
	(0.013)	(0.030)	(0.009)	(0.777)
Controls				
Size	−0.054***	−0.107*	−0.009	4.089***
	(0.012)	(0.056)	(0.007)	(0.676)
EBIT_TA	0.502***	0.858	−0.153	−14.980
	(0.153)	(0.830)	(0.088)	(9.853)
RE_TA	0.157	1.335	0.056	5.683
	(0.159)	(1.883)	(0.118)	(8.329)
Bank FE	YES	YES	YES	YES
Time FE	YES	YES	YES	YES
Number of observations	154	190	101	234
R^2	0.864	0.823	0.890	0.681

Note. This table shows the estimation results of Equation (1). Robust standard errors are clustered at the bank level and shown in parentheses. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Figure 2
Parallel trends - effect of Resolution 4,945/2021



This figure illustrates the behavior of the average Score, before and after the Resolution 4,945/2021 for both treated and control group.

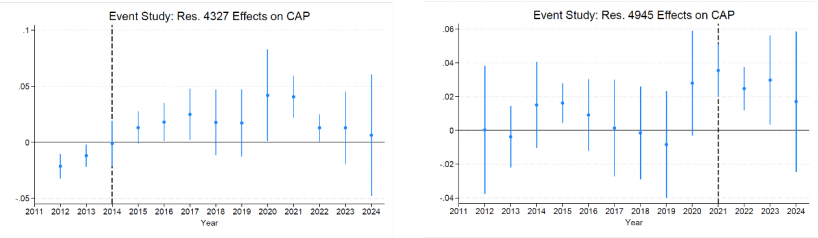
Table 4
The impact of Resolution 4,327/2014 on bank risk by E, S, and G scores
Panel B: S score

Variables	(1) CAP	(2) RWA	(3) NPL_ratio	(4) Leverage
Res4327×Treated_S	0.028***	−0.060**	0.001	−0.540
	(0.007)	(0.024)	(0.005)	(0.765)
Controls				
Size	−0.051***	−0.112*	−0.009	4.064***
	(0.012)	(0.057)	(0.008)	(0.663)
EBIT_TA	0.545***	0.776	−0.142	−14.857
	(0.135)	(0.815)	(0.091)	(9.922)
RE_TA	0.147	1.369	0.030	5.229
	(0.150)	(1.901)	(0.114)	(8.248)
Bank FE	YES	YES	YES	YES
Time FE	YES	YES	YES	YES
Number of observations	154	190	101	234
R^2	0.872	0.824	0.890	0.681

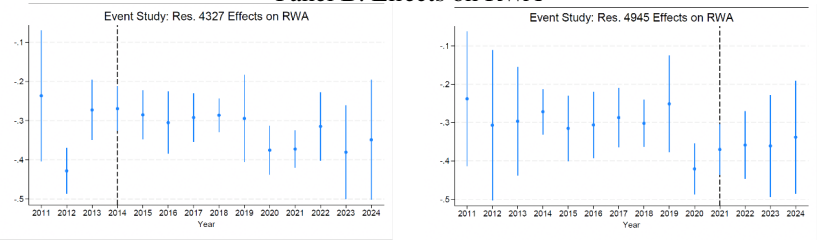
Note. This table shows the estimation results of Equation (1). Robust standard errors are clustered at the bank level and shown in parentheses. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Figure 3
Event study plots

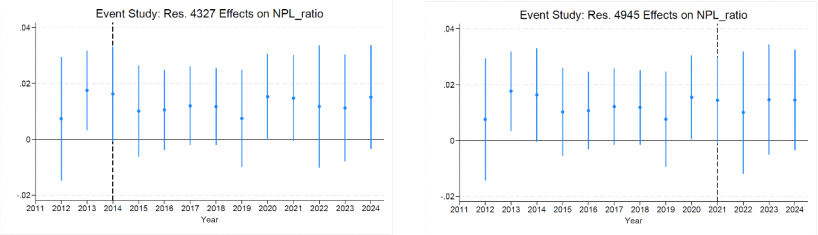
Panel A. Effects on CAP



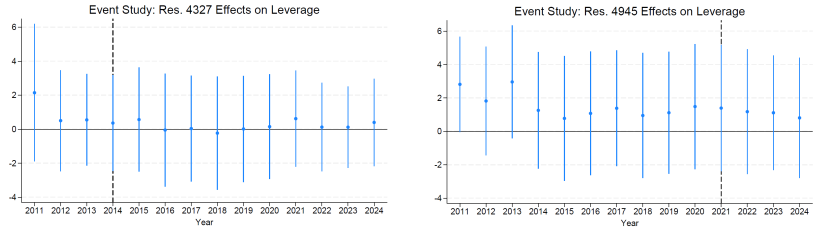
Panel B. Effects on RWA



Panel C. Effects on NPL_ratio



Panel D. Effects on Leverage



This figure shows the dynamic relationship between ESG scores and bank risk proxies relative to Resolutions 4,327/2014 and 4,945/2021.

Table 4
The impact of Resolution 4,327/2014 on bank risk by E, S, and G scores
Panel C: G score

Variables	(1) CAP	(2) RWA	(3) NPL_ratio	(4) Leverage
Res4327×Treated_G	0.026***	−0.041	0.010	−0.386
	(0.007)	(0.030)	(0.008)	(0.689)
Controls				
Size	−0.051***	−0.112*	−0.006	4.062***
	(0.012)	(0.058)	(0.007)	(0.658)
EBIT_TA	0.552***	0.789	−0.120	−15.024
	(0.131)	(0.814)	(0.094)	(9.856)
RE_TA	0.183	1.330	0.072	5.267
	(0.154)	(1.911)	(0.129)	(8.274)
Bank FE	YES	YES	YES	YES
Time FE	YES	YES	YES	YES
Number of observations	154	190	101	234
R^2	0.873	0.824	0.900	0.680

Note. This table shows the estimation results of Equation (1). Robust standard errors are clustered at the bank level and shown in parentheses. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Table 5
The impact of Resolution 4,945/2021 on bank risk by E, S, and G scores
Panel A: E score

Variables	(1) CAP	(2) RWA	(3) NPL_ratio	(4) Leverage
Res4945×Treated_E	0.019	−0.042	0.011**	−0.029
	(0.012)	(0.058)	(0.004)	(0.466)
Controls				
Size	−0.054***	−0.105*	−0.008	4.081***
	(0.010)	(0.056)	(0.007)	(0.672)
EBIT_TA	0.501***	0.906	−0.122	−14.388
	(0.135)	(0.835)	(0.091)	(10.051)
RE_TA	0.131	1.333	−0.032	4.673
	(0.138)	(1.829)	(0.107)	(8.520)
Bank FE	YES	YES	YES	YES
Time FE	YES	YES	YES	YES
Number of observations	154	190	101	234
R^2	0.871	0.824	0.898	0.679

Note. This table shows the estimation results of Equation (1). Robust standard errors are clustered at the bank level and shown in parentheses. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Table 5
The impact of Resolution 4,945/2021 on bank risk by E, S, and G scores
Panel B: S score

Variables	(1) CAP	(2) RWA	(3) NPL_ratio	(4) Leverage
Res4945×Treated_S	0.012	−0.056	0.005	−0.068
	(0.013)	(0.065)	(0.005)	(0.469)
Controls				
Size	−0.053***	−0.112*	−0.007	4.077***
	(0.011)	(0.061)	(0.007)	(0.669)
EBIT_TA	0.506***	0.892	−0.131	−14.380
	(0.141)	(0.813)	(0.091)	(10.046)
RE_TA	0.161	1.276	0.044	4.617
	(0.140)	(1.839)	(0.101)	(8.395)
Bank FE	YES	YES	YES	YES
Time FE	YES	YES	YES	YES
Number of observations	154	190	101	234
R^2	0.867	0.825	0.892	0.679

Note. This table shows the estimation results of Equation (1). Robust standard errors are clustered at the bank level and shown in parentheses. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Table 5
The impact of Resolution 4,945/2021 on bank risk by E, S, and G scores
Panel C: G score

Variables	(1) CAP	(2) RWA	(3) NPL_ratio	(4) Leverage
Res4945×Treated_G	0.014	−0.044	0.001	−0.389
	(0.014)	(0.059)	(0.004)	(0.451)
Controls				
Size	−0.054***	−0.106*	−0.009	4.086***
	(0.010)	(0.056)	(0.007)	(0.668)
EBIT_TA	0.496***	0.924	−0.143	−14.091
	(0.137)	(0.851)	(0.088)	(9.911)
RE_TA	0.149	1.301	0.028	4.626
	(0.143)	(1.834)	(0.109)	(8.150)
Bank FE	YES	YES	YES	YES
Time FE	YES	YES	YES	YES
Number of observations	154	190	101	234
R^2	0.868	0.824	0.890	0.680

Note. This table shows the estimation results of Equation (1). Robust standard errors are clustered at the bank level and shown in parentheses. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

capital buffers, as these institutions would face greater pressure to increase their capital. While the interaction term remains positive and marginally significant for the capital ratio in the low-buffer subsample, its magnitude is considerably smaller than in the full sample, and the reduction in risk-weighted assets is no longer statistically significant. We do not find significant effects for banks with higher initial capital buffers. These findings do not support the view that the baseline results are driven by Basel III. This interpretation is also consistent with the institutional characteristics of the Brazilian banking system, where banks maintained capital ratios comfortably above the Basel II and III minimum requirements, resulting in well-capitalized banks even after the implementation of the Basel Accords. Consequently, the incentives to increase capital in response to Basel III were significantly weaker than in banking systems operating closer to the regulatory minimum.

Third, to address concerns that our findings may be influenced by overlapping macroeconomic and regulatory shocks, we re-estimate the models using narrower event windows surrounding each regulatory intervention. Specifically, we restrict the sample to 2012–2017 for Resolution 4,327/2014 and to 2019–2024 for Resolution 4,945/2021, thereby excluding observations more likely to be affected by the aftermath of the global financial crisis, the gradual implementation of Basel III, and other structural changes. The results show that the positive effect of Resolution 4,327/2014 on banks' capital ratios remains economically and statistically significant, with a coefficient very similar to that obtained in the full sample, suggesting that the main finding is not driven by broader temporal trends. While the estimated reduction in risk-weighted assets is no longer statistically significant, this appears to reflect the reduced sample size and shorter post-treatment horizon rather than a fundamental change in the estimated relationship. For Resolution 4,945/2021, the restricted-window estimates remain statistically insignificant across all risk measures, consistent with the baseline results.

Overall, these sensitivity analyses indicate that our conclusions are unlikely to be driven by overlapping regulatory reforms or macroeconomic shocks and robust to alternative sample windows.

5. Conclusion

In this paper, we study whether and how the National Monetary Council's Resolutions 4,327/2014 and 4,945/2021 affected the relationship between banks' ESG performance and their risk profiles. Using a DiD design, we identify the causal effects of these two key regulatory changes on the Brazilian banking sector between 2010 and 2024.

Our findings show that Resolution 4,327/2014, which mandated the adoption of PRSA, served as a regulatory inflection point for sustainable bank risk management in Brazil. Low-ESG banks, which initially lagged in ESG integration, significantly reduced their risk levels after the regulation's implementation. This risk reduction was particularly evident in capital adequacy improvements and lower risk-weighted asset ratio, indicating stronger resilience and governance discipline following the introduction of mandatory ESG frameworks. An important finding is that these effects are concentrated in the social and governance dimensions of ESG, whereas the environmental pillar does not exhibit statistically significant effects. This suggests that the initial implementation of Brazil's ESG banking framework primarily strengthened banks' governance and social responsibility practices, with environmental considerations playing a less prominent role during the period analyzed.

In contrast, Resolution 4,945/2021 had a more modest effect. While it reinforced disclosure quality, climate-risk integration, and governance oversight, it did not substantially alter banks' risk behavior. By the time of its issuance, most institutions had already internalized the ESG practices introduced under Resolution 4,327/2014, suggesting regulatory convergence and diminishing marginal returns from subsequent reforms. The 2021 regulation thus functioned more as a standardization and transparency initiative rather than a regulatory change.

More broadly, these results underscore the time-sensitive nature of regulatory effectiveness. Early regulatory interventions that impose material requirements tend to yield the strongest effects on bank risk management, whereas later interventions consolidate gains by harmonizing standards and

reducing information asymmetries but generate weaker direct impacts on financial outcomes.

From an international perspective, the Brazilian evidence mirrors global regulatory experiences. Policies such as the Paris Agreement, the European Union's Sustainable Finance Disclosure Regulation (SFDR), and China's Green Credit Policy have followed similar trajectories: early-stage regulations drive structural change, while later-stage policies focus on refining disclosure, comparability, and monitoring. Like the EU's SFDR, Brazil's Resolutions 4,327/2014 and 4,945/2021 demonstrate that mandatory ESG supervision frameworks can improve risk discipline and enhance systemic stability, even in emerging markets.

Overall, this study provides empirical evidence that ESG regulation can act as an effective driver for risk convergence in the banking sector. By mandating ESG-lagging institutions to integrate social, environmental, and climate considerations into their risk management systems, regulators can effectively narrow the gap in sustainability performance across financial institutions and, as a result, "green" the banking system. Future research could extend this analysis by incorporating unlisted financial institutions, testing alternative ESG data to account for heterogeneity in ESG scores, and evaluating cross-country differences in regulatory sequencing between developed and emerging markets. A comparative assessment of Brazil's experience with other regulatory regimes, such as the EU Taxonomy or the Monetary Authority of Singapore's Green Finance Framework, could further clarify how policy design shapes the effectiveness of ESG integration in banking.

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Conflict of interest Nothing to declare.

Data availability The ESG and financial data used in this study were obtained from LSEG Data & Analytics (formerly Refinitiv) under license and cannot be redistributed by the authors. COSIF data from the Central Bank of Brazil are publicly available.

Artificial intelligence During the preparation of this work, the authors used ChatGPT in order to assist with refining language and ensuring clarity of expression. After using these services, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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