

Between solvency and performance: portfolio efficiency under regulatory constraints in the Brazilian (re)insurance market

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Abstract

Purpose – To examine whether regulatory constraints allow (re)insurance companies to build adequately diversified portfolios capable of expanding the efficient frontier and generating superior risk-adjusted returns in different macroeconomic scenarios. Using counterfactual simulations with and without regulatory constraints, the study assesses how solvency regulations affect portfolio risk and financial performance.

Theoretical framework – The study is grounded in modern portfolio theory and incorporates coherent risk measures, particularly conditional value at risk (CVaR). The theoretical framework discusses the relationship between risk management, solvency requirements, and regulatory constraints in the insurance industry.

Design/methodology/approach – Mean-CVaR optimization models were used to identify optimal portfolio allocations that preserve insurers' solvency and evaluate the effect of changes in the allocation of admissible assets on financial performance. In addition, the probability of adverse short-term outcomes was estimated. The analysis is based on daily data for 13 market indices covering the period from 2014 to 2025.

Findings – The regulatory framework ensures solvency and financial stability, but it limits diversification in low-interest-rate environments, thereby constraining risk-adjusted returns. Unconstrained portfolios achieved higher returns and greater diversification. A moderate allocation of 1-5% to alternative assets expanded the efficient frontier without substantially increasing portfolio risk.

Practical and social implications of the research – The findings suggest that regulatory requirements should be periodically reassessed to better balance prudential oversight and portfolio efficiency. Greater regulatory flexibility may allow insurers to optimize asset allocation without compromising solvency.

Originality/value – This study provides evidence of the direct effects of regulatory constraints on portfolio diversification, solvency, and risk-adjusted returns, contributing to ongoing discussions on prudential regulation and asset management in the Brazilian (re)insurance industry.

Keywords: Asset management, regulatory constraints, portfolio diversification, portfolio optimization, conditional value at risk (CVaR).

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1 Introduction

The Brazilian insurance market consists of (re) insurers, open-ended supplementary pension funds, and capitalization companies. It plays a significant role in the national economy. In 2024, the industry accounted for 6.4% of GDP, and this figure is expected to reach 10% by 2030 (CNSeg, 2023, 2024). It is a heavily regulated industry whose entities are large institutional investors (Cardoso et al., 2024), which pose a significant risk of systemic contagion (Barucca et al., 2021; Carvalho & Guimarães, 2024; Cummins & Weiss, 2014; Elyasiani et al., 2016). Thus, asset management is essential for their stability (Diehl et al., 2022; Eckert, 2019). This aspect is particularly relevant in Brazil, where banks and insurance companies are highly integrated (bancassurance) (Carvalho & Guimarães, 2022; Peng et al., 2017).

Due to its importance, there is significant concern about the prudential regulation of assets backing technical reserves (E. Flores et al., 2021a; Pradhan et al., 2016), particularly the rules defining the eligibility of investments underpinning actuarial obligations (Carvalho & Carvalho, 2019).

The literature has documented concerns about the efficient management of assets for supplementary pension entities (Duarte et al., 2017; Li & Forsyth, 2019), life insurance companies (Rao et al., 2018), and even non-life insurance companies (Badaoui & Fernández, 2013). A common theme is developing investment strategies that ensure these entities' long-term solvency by minimizing their probability of default (Dong & Wang, 2018). However, there is a lack of empirical analyses on the effectiveness of industry-specific regulations (Cardoso et al., 2024; Damasceno & Carvalho, 2021).

In Brazil, CMN Resolution No. 4,993/2022 (RCMN4993) regulates the allocation of collateral assets by setting limits based on asset class and issuer. The resolution aims to ensure adequate remuneration, security, and liquidity in accordance with Decree-Law No. 73/1966. However, the limits have not changed since 2015, reflecting regulatory inflexibility despite significant changes in the macroeconomic environment, such as prolonged periods of low interest rates.

This rigidity is particularly relevant in scenarios with low base interest rates (Ikeda & Carvalho, 2022), as restrictions on diversification may compromise portfolio performance, especially given the requirement to allocate a minimum amount to fixed-income assets. Table 1 shows

the investment limits for collateral assets permitted by RCMN4993 by asset class.

However, it remains uncertain whether investing at the maximum levels imposed by RCMN4993 effectively fulfills its primary objective of enabling higher financial returns without compromising risk levels that are compatible with preserving asset value. The objective of this study is to evaluate if these limits permit the development of sufficiently diversified and efficient portfolios that can expand the efficient frontiers for investment. This evaluation considers recent dynamics in the Brazilian economic landscape and the inclusion of alternative assets in a counterfactual context.

To this end, this study estimates hypothetical portfolios that mimic the composition of the collateral portfolios underpinning these entities' current and future liabilities. This includes the incorporation of alternative assets across four distinct scenarios. This approach is based on models inspired by the asset-liability management (ALM) framework and tested under two conditions: with and without regulatory limits. Optimization is performed using the mean-CVaR model, which is widely used in the literature for similar problems, such as in public servants' pension schemes (Damasceno & Carvalho, 2021) and closed supplementary pension entities (Cardoso et al., 2024).

2 Theoretical framework

The literature extensively covers the topic of optimizing the investment portfolios of life insurers and supplemental pension entities, given the long-term nature of these products and the need to align assets with actuarial obligations (Chen et al., 2006; Diehl et al., 2022; Eckert, 2019). In contrast, analysis of non-life insurers is less common despite its relevance since these institutions operate with short-term liabilities and high capital turnover (Carvalho & Carvalho, 2019). In this context, ruin theory is widely used to define optimal investment strategies in stochastic models (Badaoui & Fernández, 2013; Carvalho & Cardoso, 2021).

Actuarially, the objective is to minimize an entity's probability of ruin; economically, the goal is to maximize expected utility through production functions. Both objectives fall within the framework of risk theory and stochastic control, which is widely applied to multi-period allocation problems (Haberman & Sung, 2005; Yiu, 2004).

Table 1

Maximum allocation limits by asset class relative to plan assets according to CMN Resolution No. 4,993/2022

Asset Classes		4,993/2022	Type		
Fixed income (FI) – Up to 100%	Government bonds	100%	Federal domestic public debt securities		
		100%	CRTNs		
	Investment funds	100%	Funds investing in federal domestic public debt securities		
		100%	Government bond index funds		
		50%	Fixed-income funds		
		50%	Fixed-income index funds		
		25%	FIDCs (senior shares) and FICFIDCs		
		Other assets	75%	Securities or other fixed-income financial assets issued by publicly traded companies	
			75%	Infrastructure debentures	
			50%	Debt instruments issued by financial institutions authorized by the Central Bank of Brazil	
			25%	Securities or other fixed-income financial assets issued by special-purpose entities	
			25%	CRI and CRAs	
			25%	Debt instruments issued by financial organizations of which Brazil is a member	
			25%	Fixed-income securities or financial instruments not listed above	
	Equities – Up to 49%		Shares	100%	Shares, subscription warrants and receipts, securities depositary receipts, and equity-referenced funds listed on the Novo Mercado segment
75%		Shares, subscription warrants and receipts, securities depositary receipts, and equity-referenced funds listed on the Level 2 segment			
50%		Shares, subscription warrants and receipts, securities depositary receipts, and equity-referenced funds listed on the Level 1 segment			
25%		Shares, subscription warrants and receipts, securities depositary receipts, and equity-referenced funds listed on the Basic segment			
Investment funds		100%		Funds investing in shares, subscription warrants and receipts, securities depositary receipts, and equity-referenced funds listed on the Novo Mercado segment	
		75%		Funds investing in shares, subscription warrants and receipts, securities depositary receipts, and equity-referenced funds listed on the Level 2 segment	
		50%		Funds investing in shares, subscription warrants and receipts, securities depositary receipts, and equity-referenced funds listed on the Level 1 segment	
		50%		Equity index funds	
		50%	Equity-index-referenced funds		
		25%	Equity funds		
		25%	Profit-sharing debentures		
Real estate – Up to 20%		Investment funds	100%	FIIIs or FICFIIIs	
		Foreign exchange exposure – Up to 20%	Government bonds	100%	Federal public debt securities whose returns are linked to foreign-currency exchange rates
				50%	Securities representing corporate debt issued by Brazilian publicly traded companies
	Investment funds		100%	Foreign-exchange investment funds	
			100%	External-debt fixed-income funds	
			100%	Offshore investment funds	
			100%	Offshore investment index funds	
			100%	Multimarket funds whose investment policies allow investments in assets or derivatives that carry foreign-exchange risk	
			75%	Equity funds investing in Level 1 BDRs	
			50%	Funds investing in corporate debt issued by Brazilian publicly traded companies	
			Other assets	100%	COEs with principal protection
	75%			BDRs	
	25%			Fixed-term deposits with maturities of up to six months	
	25%			Certificates of deposit	
25%	Securities issued by central governments of foreign jurisdictions with ratings of AA- or higher				
Other assets – Up to 10%	Investment funds	100%		Multimarket funds	
		75%		Equity funds investing in the Access Market	
	Other assets	100%	COEs with principal protection		
		75%	FIPs		
		25%	COEs with principal at risk		
		25%	Certified Emission Reductions and carbon credits		

Source: Prepared by the authors.

In the non-life insurance segment, risk dynamics are heterogeneous. While some portfolios, such as auto insurance, exhibit relative stability, others are more volatile and require greater flexibility in asset allocation and liquidity management (Berry-Stölzle, 2008; Lopes & Carvalho, 2022). Furthermore, the uncertainty associated with valuing liabilities at market value increases the complexity of management, particularly for insurance companies with multiple lines of business (Haneveld et al., 2010). Thus, efficiently managing collateral assets is essential to the financial sustainability of these institutions (Badaoui & Fernández, 2013; Bezerra & Corrar, 2006).

Several studies have been conducted to identify the best method for the idiosyncratic dynamics of various insurance industry segments. Some of this literature uses benchmarks to define optimal portfolios. van Staden et al. (2024) propose maximizing the performance of dynamic portfolios relative to a benchmark to outperform it and ensure the company's capital adequacy. In this context, the literature often incorporates utility functions (either implicitly or explicitly) and explores various benchmark assets when constructing strategies.

Meanwhile, Yu et al. (2012) developed a hybrid algorithm combining the Levenberg-Marquardt method, an optimization method for finding the minimum of a function describing risks in an investment portfolio, with multi-period evolutions of a strategy for long-term asset management in insurance companies. However, Lim and Wong (2010) point out that the performance of these strategies can be sensitive to the adopted macroeconomic scenario, which can lead to an underestimation or overestimation of the results.

Another application in the insurance sector is that of Lampenius and Schmautz (2013), who demonstrated that optimization with the explicit inclusion of risk capital as a function of the total risk of the investment portfolio allows one to determine a necessary minimum overall risk capital for the company. Their results highlight the advantages of ALM over asset-focused management, while also underscoring the risks of disregarding the interdependence between these dimensions when determining required capital.

In this context, ALM models are important tools for financial management in insurance companies because they identify adverse scenarios and enable proactive risk management. They are flexible and have a broad range of applications, which allows them to capture different sources of risk, such as underwriting, credit, liquidity, and market risk (Hurtado, 2008).

Cardoso et al. (2024) note that the actuarial literature on the use of ALM in pension plans is relatively recent but already includes a significant number of empirical applications (Andongwisye et al., 2018; Lauria & Consigli, 2017; Toukourou & Dufresne, 2018). This expansion stems from the stochastic nature of these models, whose parameters allow for a more realistic representation of economic and actuarial variables (e.g., interest rates, inflation, prices, and loss ratios). This overcomes the limitations of deterministic approaches (Ribeiro, 2015; Valladão, 2008). Pachamano et al. (2017), for example, use ALM to determine optimal investment strategies for a pension fund capable of generating sufficient returns to cover the institution's liabilities.

Papayiannis (2023) analyzes the effects of applying ALM models and their suitability for uncertain scenarios, focusing on the financial and insurance sectors. Combining these models with stochastic programming allows for the incorporation of multiple correlated sources of risk into a single framework for assets and liabilities. Furthermore, they enable dynamic portfolio rebalancing while adhering to operational or regulatory constraints (Kouwenberg & Zenios, 2008).

Using discrete-time ALM to simulate the balance sheets of life insurance companies, Bohnert et al. (2015) and Gerstner et al. (2008) identified behavioral patterns of the variables associated with the products offered. This allowed them to assess the sensitivity of the simulated portfolios and the impact of the parameters on risk exposure. Similarly, Diehl et al. (2022) used ALM to analyze the influence of life insurance products on insurers' balance sheets in low-interest-rate scenarios. They sought to identify portfolios that are more resilient to shocks in the capital markets.

In low-interest-rate scenarios where traditional, lower-risk assets offer less attractive returns, it is crucial for institutions to adopt more efficient allocation strategies (Ikeda & Carvalho, 2022). However, these entities operate under significant regulatory constraints that limit diversification and complicate active portfolio management (Chen & Hieber, 2016).

In this context, Damasceno and Carvalho (2021), by analyzing public servants' pension schemes with ALM and Conditional Value at Risk (CVaR) minimization, demonstrate that portfolios subject to asset-class-based regulatory restrictions are twice as volatile as portfolios constructed without such limitations. Additionally, Cardoso et al. (2024) evaluate the capacity of closed supplementary pension entities to generate financial returns sufficient to cover actuarial liabilities under a regulatory-restriction scenario, also by asset class.

The results indicate a high risk of low or even negative long-term returns, with losses primarily absorbed by the beneficiaries of this plan.

This study contributes to the field by adapting an optimization framework inspired by ALM (Cardoso et al., 2024; Damasceno & Carvalho, 2021) to evaluate the efficiency of collateral assets in the Brazilian (re)insurance market under regulatory constraints. Specifically, we evaluate the capacity of (re)insurers' collateral assets to generate returns in various macroeconomic scenarios while considering the potential impact of simulated regulatory relaxation.

3 Methodology

Building on the optimization framework developed by Damasceno and Carvalho (2021) for evaluating the pension sector, we will adapt the method for use in the (re) insurance industry. The main difference between the two is that (re)insurance management is inherently short-term. Therefore, there is no actuarial target to pursue; rather, the goal is to manage the underlying assets as well as possible in order to improve the risk-return ratio in the short term. Furthermore, (re)insurance contracts are usually annual (Euphasio Jr. & Carvalho, 2022), reducing the need for complex intertemporal modeling of liabilities, as used in pension funds and long-term life insurance. Therefore, we will take a more parsimonious approach to liabilities, focusing on evaluating the efficiency with which collateral assets are allocated under regulatory constraints.

This method can identify optimal portfolio compositions to ensure entities' solvency and the impact of changes in collateral asset allocation on financial results. It is also possible to measure the probability of adverse short-term outcomes, as Cardoso et al. (2024) did for closed supplementary pension entities.

This study is conceptually based on the ALM framework but does not aim to implement a complete, dynamic ALM model. Rather, it takes a parsimonious approach, focusing on asset allocation under regulatory constraints and using the solvency ratio as a proxy for the relationship between assets and liabilities.

3.1 Solvency ratio and estimated optimal return

The solvency ratio reported by (re)insurance entities at time $t = 0$ is measured by Equation 1. The objective is to provide an actuarial metric, expressed as the ratio of financial assets to the amount allocated to

cover the company's present and future obligations, both valued at market value (MtM), to monitor the entity's financial position.

$$S_t = \frac{A_t}{P_t} \quad (1)$$

such that S_t represents the entity's technical equilibrium level, A_t represents total assets, and P_t represents the insurer's present and future liabilities at time t . It should be noted that this study is based on an aggregated and normative approach constructed using assets representative of the classes permitted by regulation, rather than on individualized data from insurers. This approach allows the results to be interpreted more generally and applied to different companies, although it involves simplifying the structure of liabilities.

A company is in a surplus or actuarial equilibrium when $S_t \geq 1$, and in deficit when $S_t < 1$. In the latter case, it is possible to algebraically estimate the additional rate of return (Equation 2) required to achieve equilibrium at time t ($i_t^{\text{optimized portfolio}}$), as developed by Damasceno and Carvalho (2021):

$$i_t^{\text{optimized portfolio}} = \begin{cases} (1+i_t) \times (1+MA_t) - 1, & \text{if } A_t < P_t \\ MA_t, & \text{if } A_t \geq P_t \end{cases} \quad (2)$$

where i_t refers to the estimated return such that $S_t = 1$ and must be annualized by decomposing the rate over D years according to Equation 3. Meanwhile, MA_t represents the annual rate of return that the (re)insurance entity should pursue to exceed equilibrium.

$$i_t = (1+i)^{\frac{1}{D}} - 1 \quad (3)$$

3.2 Optimization constraints

Once the optimal portfolio return is determined, scenarios that achieve or exceed it while adhering to the investment limits set forth in RCMN4993 are identified. These limits will serve as one of the constraints for the model's optimization. The second constraint corresponds to CVaR, which, despite being related to VaR in formulation, is preferred in the literature because it satisfies the four properties of a coherent risk measure (Artzner et al., 1999). VaR, however, fails the principle of subadditivity (Carvalho & Sanguino, 2024). CVaR refers to the conditional expected loss of the portfolio beyond the VaR threshold (Krokhmal et al., 2001; Panjer & Fia, 2002), which, in this study, will be set at the 95% confidence interval level. We will closely follow Damasceno and Carvalho (2021).

The estimate of the worst-case value in the α -quantile (VaR_α) is defined by Equation 4:

$$\text{VaR}_\alpha = -z_\alpha \sqrt{w^T \Sigma w} = \zeta_\alpha(\xi) \quad (4)$$

where w is the portfolio allocation weight vector, Σ is the matrix of linear correlations among the assets, and z_α is the quantile to the left of the normal (0,1) curve. However, by adopting this distribution as an assumption, parametric VaR ignores important properties of asymmetric series, such as those obtained from market data (Damasceno & Carvalho, 2021; Sogiakas, 2017).

CVaR, on the other hand, is given by Equation 5, which calculates the weighted average of extreme losses beyond the VaR quantile:

$$\text{CVaR}_\alpha(w, \zeta) = \zeta + (1 - \alpha)^{-1} \int_{\xi \in \mathbb{R}} [f(w, \xi) - \zeta]^+ p(\xi) d\xi \quad (5)$$

where $f(w, \xi)$ represents the portfolio loss function and $[f(w, \xi) - \zeta]^+$ denotes exceeding the global quantile ζ . Thus, the relationship between the measures is (Equation 6):

$$\text{CVaR}_\alpha(w, \zeta) = \mathbb{E}[\xi \mid \xi \geq \zeta_\alpha(\xi)] = \mathbb{E}[\xi \mid \xi \geq \text{VaR}_\alpha] \quad (6)$$

CVaR will be optimized and numerically approximated, analogous to the procedures described by Hernandez et al. (2022) and Rockafellar and Uryasev (2000) and verified by Krokhmal et al. (2001). The numerical approximation is performed as follows:

$$\text{CVaR}_\alpha(w, \zeta) \approx \min \left\{ \zeta + (1 - \alpha)^{-1} \sum_{s=1}^S [f(w, \xi_s) - \zeta]^+ p_s \right\} \quad (7)$$

such that, in simplified form, the term z_s :

$$[f(w, \xi_s) - \zeta]^+ = z_s \Leftrightarrow z_s \geq f(w, \xi_s) - \zeta \geq 0$$

The problem given by Equation 7 is solved by finding the optimal allocation weights (Equation 8) $w_n, n = 1, 2, 3, \dots, N$, which represent the proportion of each financial instrument in the insurer's investment portfolio and are expressly limited by RCMN4993.

$$w_n^{\min} \leq w_n \leq w_n^{\max} \quad (8)$$

3.3. Simulation of future risk scenarios

The assets selected to compose the groups within the scope of RCMN4993 are index funds ("ETFs") that represent their respective markets. These ETFs are preferred for their indirect exposure to multiple securities and companies, which broadens the diversification of the sample. This principle aligns with Markowitz's (1952) work, which states that combining assets with different

risk profiles and correlations reduces the total risk of a portfolio without necessarily compromising expected returns. Future scenarios will be generated at each point in time t based on the correlated annual returns of the assets using the framework developed by Dempster et al. (2003). The exceptions to the model are the future prices of equity assets, which are generated using a geometric Brownian motion (Equations 9 and 10) that takes into account stochastic differential equations:

$$\zeta_{RVt} = \zeta_{RV(t-1)} e^{\left(\mu - \left(\frac{1}{2} \right) \sigma^2 \right) dt + \sigma \varepsilon \sqrt{dt}} \quad (9)$$

where w_{it} follows a Wiener process, $N(0, \Delta)$, and $t < t + \Delta$, and the variance-covariance matrix among assets is:

$$dW_i \times dW_j = \rho_{ij} dt \quad (10)$$

where the main diagonal of the resulting matrix refers to the correlation of the asset itself, i.e., $\rho_{ii} = 1, \forall i \geq 1$. According to Dempster et al. (2003), this structure allows for the joint modeling of the stochastic trajectories of different assets such that random shocks affecting their prices are not independent of one another.

Simulating the future prices of representative assets for each investment class makes it possible to track the evolution of returns and compare the theoretical results provided by the standard for the Brazilian (re)insurance industry to those of a portfolio without allocation constraints. For the intertemporal analysis, four historical periods were defined based on the Brazilian economic cycle, which is characterized by alternating phases of expansion and recession. These periods are defined by the official dates established by the Economic Cycle Dating Committee (CODACE) (see Table 2). Identifying these cycles is essential for anticipating trends in economic variables and informing public policy decisions and investment strategies that minimize adverse impacts or maximize opportunities, as Cunha (2017) discusses.

The returns on the assets used in the simulations were calculated annually and aggregated to construct statistics for each period. The mean and variance-covariance matrix parameters were estimated based on the observed historical series in each time window. Stochastic scenarios were generated for each period using Monte Carlo simulation, totaling 100,000 trajectories for asset returns. The portfolio composition remained fixed throughout each simulation without dynamic rebalancing to isolate the effects of the initial allocation under different market conditions. All procedures were implemented using R software (version 4.4.1) (Supplementary Material Data 3 – R script).

Table 2

Economic periods selected for the historical evaluation of the simulated portfolio

Periods	Years	CODACE Dating	Events	Description
1	Sep 2014 to Sep 2016	Recession	Pre-Impeachment	A period characterized by high inflation and elevated interest rates, accompanied by economic challenges and political instability, which culminated in the impeachment of President Dilma Rousseff. Operation Car Wash (<i>Lava Jato</i>) significantly impacted strategic sectors, such as oil and construction. This impacted the market value of major firms and contributed to the economic downturn.
2	Sep 2017 to Sep 2019	Expansion	Post-Impeachment	A period marked by economic reforms, including labor market reform and initial discussions about pension reform. During this time, the SELIC policy rate gradually declined from 14.25% to 6.5%.
3	Sep 2020 to Sep 2021	Recession	COVID-19	A period spanning from the first documented case of COVID-19 in Brazil through the administration of the second vaccine dose. This period coincided with the historic reduction of the SELIC policy rate to 2% and heightened volatility in global financial markets.
4	Sep 2022 to Sep 2025	-	Current Economic Environment	A period marked by post-pandemic economic recovery, rising inflation, and the Central Bank's subsequent increase in the policy interest rate to 14.9%.

Source: Prepared by the authors.

4 Analysis of results

4.1 Database and descriptive statistics

The assets analyzed in this study were collected from Bloomberg and ANBIMA. They cover the asset classes permitted by RCMN4993, except for the CDI and the U.S. dollar, which are used as performance benchmarks. The alternative group, comprising SMLL, ISE, and GBTC, was included due to its speculative nature. SMLL consists of small-cap companies associated with higher risk and growth potential. ISE reflects the performance of companies committed to environmental, social, and governance (ESG) principles. GBTC is linked to Bitcoin, a highly volatile cryptocurrency widely adopted by investors in recent years (Souza & Carvalho, 2024). Including this group enables an evaluation of the potential benefits of diversification and the resulting risk-return relationship from the presence of non-traditional assets in the portfolios of (re)insurers.

The selected assets were classified into the investment categories set forth in RCMN4993 according to their economic and regulatory nature. Specifically: (i) domestic fixed-income indices (IMA-B and IDA-Infra) as proxies for public and private fixed-income securities, (ii) equity indices (IBX, IGC, and SMLL) as proxies for the domestic equity class, (iii) IFIX as a proxy for real estate investments, (iv) BDRX and A-Bond as proxies for assets with international and foreign exchange exposure, and

(v) IHFA as a proxy for multimarket funds. Additionally, ISE and GBTC were included in counterfactual scenarios to evaluate their impact on portfolio diversification and efficiency. This mapping enables the regulatory limits established in the resolution to be applied in the simulations.

Monthly returns were annualized for each period. Table 3 presents descriptive statistics summarizing key risk and return metrics across different scenarios, allowing direct comparison of simulated portfolios under varying regulatory flexibility levels (Supplementary Material Data 1 – Dataset; Supplementary Material Data 2 – Codebook).

Onshore fixed-income assets, such as the CDI, which is aligned with the benchmark interest rate, IMAB, and IDA-Infra, maintained relative stability in returns, especially during periods of crisis, with lower variation in standard deviation. During the pandemic, average returns declined, notably for the CDI (4.83%) and IMAB (7.42%), followed by a partial recovery in the current environment. This indicates greater resilience during times of economic instability. In contrast, equity and real estate assets (IGC, SMLL, and IFIX) exhibited high volatility with sharp declines during the pandemic. The IGC and SMLL recorded significant declines of -29.18% and -40.01%, respectively, demonstrating greater sensitivity to economic fluctuations.

Alternative and international assets, such as GBTC and BDRX, are highly sensitive to global markets and speculation associated with non-traditional assets, as reflected by the higher standard deviations observed.

Table 3
Descriptive statistics for selected assets across four economic periods

Period	Pre-impeachment (2014–2016)	Post-impeachment (2017–2019)	COVID-19 (2020–2021)	Current Period (2022–2025)
CDI	11.28%	9.54%	4.83%	12.35%
<i>Average</i>				
Minimum	7.45%	-6.30%	2.16%	10.80%
Maximum	14.13%	14.13%	10.93%	13.65%
Standard Deviation	2.09%	3.05%	2.24%	1.09%
Dollar	21.38%	3.26%	11.88%	3.26%
<i>Average</i>				
Minimum	-22.76%	24.65%	-18.54%	-13.32%
Maximum	74.28%	34.96%	48.35%	28.05%
Standard Deviation	20.62%	13.26%	16.69%	9.99%
IMAB	8.76%	16.31%	7.42%	7.56%
<i>Average</i>				
Minimum	-13.32%	-2.45%	-1.85%	-2.49%
Maximum	30.41%	31.45%	31.21%	17.78%
Standard Deviation	10.09%	7.01%	7.05%	4.61%
IDA-Infra	13.23%	11.94%	8.96%	9.26%
<i>Average</i>				
Minimum	8.54%	-4.55%	0.52%	1.72%
Maximum	21.57%	21.17%	18.58%	21.71%
Standard Deviation	2.99%	3.98%	3.46%	4.60%
IGC	1.09%	22.96%	8.89%	6.13%
<i>Average</i>				
Minimum	-20.01%	4.60%	-29.18%	-18.71%
Maximum	27.54%	57.38%	84.68%	29.17%
Standard Deviation	10.07%	11.40%	22.25%	12.32%
IFIX	1.01%	18.00%	4.68%	5.96%
<i>Average</i>				
Minimum	-23.67%	3.90%	-12.32%	-10.65%
Maximum	29.92%	49.55%	36.42%	24.79%
Standard Deviation	10.10%	12.37%	10.93%	8.93%
A-Bond	3.33%	2.73%	1.30%	2.55%
<i>Average</i>				
Minimum	-4.93%	2.34%	-11.16%	-12.32%
Maximum	9.75%	9.89%	13.04%	11.95%
Standard Deviation	3.03%	2.50%	5.53%	5.39%
BDRX	34.13%	16.78%	30.34%	23.11%
<i>Average</i>				
Minimum	-11.47%	16.80%	-23.15%	-33.72%
Maximum	74.18%	62.35%	90.17%	74.49%
Standard Deviation	18.86%	15.54%	25.85%	24.50%
IBX	0.02%	24.93%	7.44%	7.17%
<i>Average</i>				
Minimum	-24.47%	0.31%	-32.07%	-17.46%
Maximum	32.70%	71.46%	86.18%	30.43%
Standard Deviation	11.99%	11.58%	21.02%	12.34%
IHFA	11.70%	11.70%	7.01%	9.07%
<i>Average</i>				
Minimum	4.74%	-4.36%	-2.44%	2.83%
Maximum	19.04%	19.25%	16.32%	15.82%
Standard Deviation	4.33%	3.93%	3.28%	3.59%
SMLL	-12.24%	29.06%	8.78%	-2.98%
<i>Average</i>				
Minimum	-35.59%	12.23%	-40.01%	-30.47%
Maximum	36.84%	70.64%	85.40%	28.84%
Standard Deviation	12.77%	17.40%	29.09%	15.71%
ISE	-1.47%	13.26%	5.07%	0.02%
<i>Average</i>				
Minimum	-21.44%	9.26%	-26.40%	-28.36%
Maximum	19.11%	33.78%	60.18%	31.90%
Standard Deviation	9.20%	8.06%	16.33%	15.76%
GBTC	221.86%	320.36%	99.79%	95.79%
<i>Average</i>				
Minimum	44.44%	87.83%	-68.82%	-83.61%
Maximum	365.52%	3,322.27%	817.31%	455.76%
Standard Deviation	64.18%	488.42%	155.57%	122.20%

Source: Prepared by the authors based on data from ANBIMA and Bloomberg.

GBTC exhibits this characteristic even more prominently. Since it is not strongly correlated with other asset classes over time (Figure 1), it may offer diversification and high return potential. However, its decentralization and long-term effects require a more in-depth, multivariate analysis to understand its inherent risks and promote sustainable maturation of the product (Souza & Carvalho, 2024).

On the other hand, BDRs contribute to diversification, but they are risky due to exposure to foreign markets, which are influenced by global economic and political events. In the last two periods analyzed, BDRs posted minimum returns of -23.15% and -33.72%, respectively. This outcome is linked to the Federal Reserve's aggressive interest rate hikes to curb inflation. These hikes raised the opportunity cost and redirected investors toward offshore public and private debt securities. This heterogeneous behavior across asset classes underscores the disproportionate impact of domestic and international crises on higher-risk assets (Carvalho & Sanguino, 2024).

In summary, onshore equity assets are highly correlated, indicating similar behavior in response to economic events and local market conditions. Conversely, offshore and alternative assets exhibit low or even negative correlations with domestic assets. This suggests that these assets are less susceptible to factors affecting the Brazilian market and can serve as hedging instruments during periods of domestic economic instability. Carvalho and Sanguino (2024) support this interpretation by using Dynamic Bayesian Networks (DBNs) to demonstrate that the Ibovespa is more sensitive to risk factors linked to international investors (e.g., exchange rates and the S&P 500) than to domestic factors (e.g., inflation and interest rates). Additionally, assets exposed to exchange rates (e.g., the U.S. dollar) tend to have negative correlations with the Ibovespa and the S&P 500

during periods of pessimism, which reinforces their role as stores of value and hedging instruments.

4.2 Results of optimal portfolio estimates

This section presents the results of the optimal portfolios (under mean-CVaR) for each period based on this asset behavior. Next, the combinations that best promote diversification and risk reduction without compromising expected returns are identified, as well as the effects of a conservative relaxation of regulation.

The algorithm calculated portfolio compositions for each risk-return level. It considered allocations that optimized this relationship within the limits set by RCMN4993 ("CMN4993 Model") and, alternatively, it considered allocations without specific asset-class restrictions ("Unrestricted Model"). The results for each period are presented in Figure 2. In both models, the greatest diversification occurred during the post-impeachment period, with allocations across seven of the eight available assets. The only asset not included was U.S. A-Bonds, whose returns fell below domestic interest rates during the period. This result reflects the relative attractiveness of Brazilian fixed income in high-interest-rate environments. This finding is consistent with the work of Cardoso et al. (2024), who emphasize the central role of domestic instruments in such regimes.

The allocations in the CMN4993 Model predominantly consist of fixed-income assets, which is consistent with the greater regulatory flexibility of this asset class. Consequently, during periods of domestic economic prosperity, returns are limited and do not keep pace with the equity market. This occurred during the pre-impeachment period when the restricted portfolio achieved an average annual return of 20%, which was below the 25% maximum return observed in the IBX.

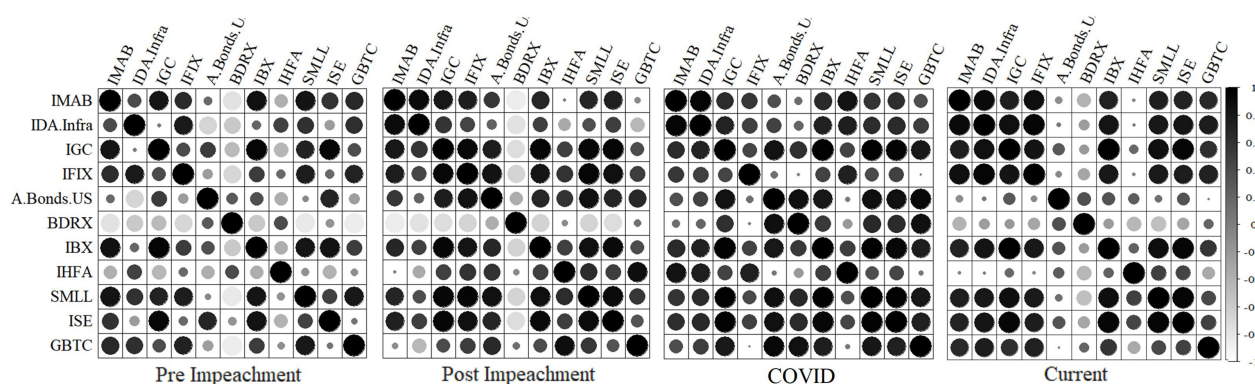


Figure 1. Correlations observed among investment classes by period

Source: Prepared by the authors

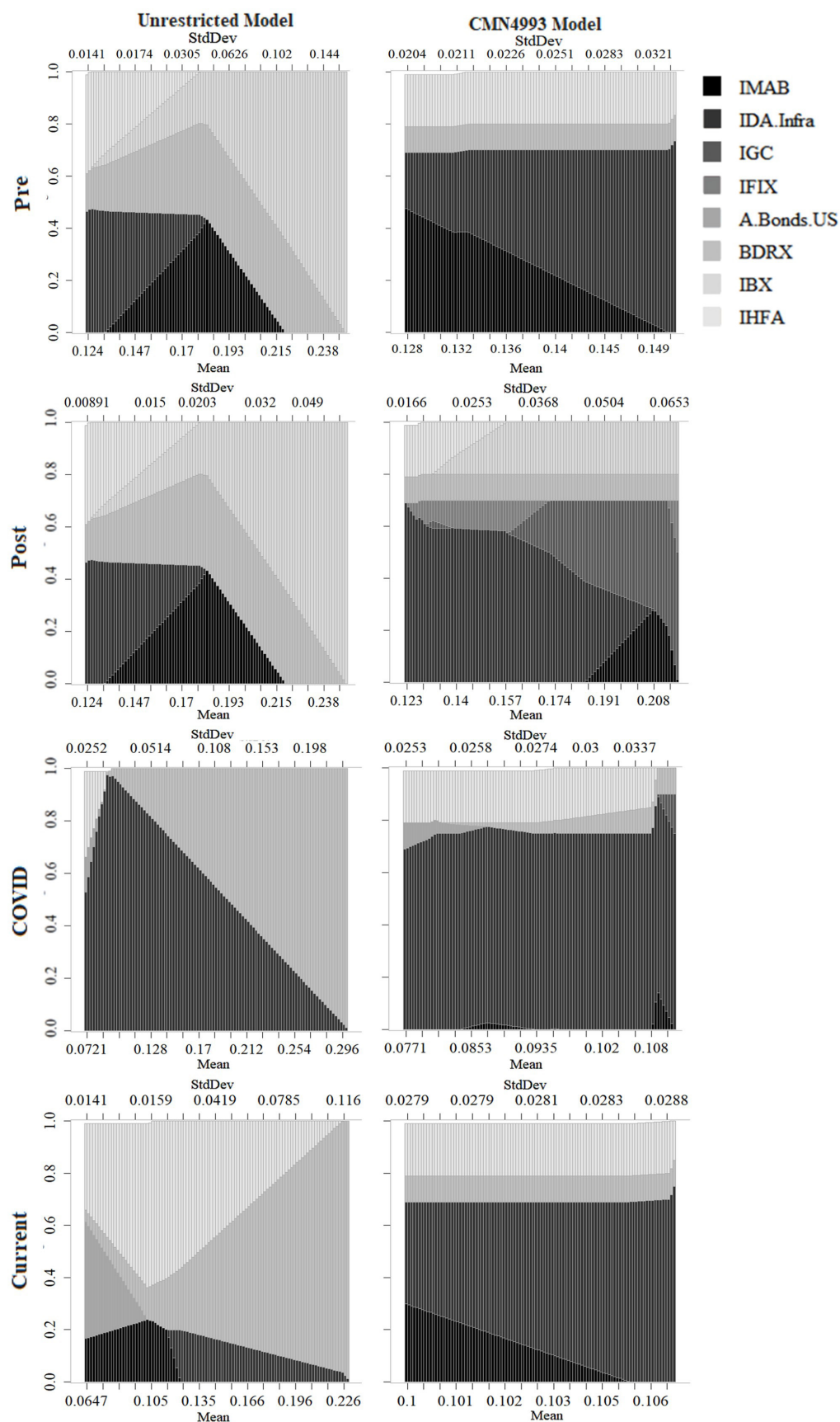


Figure 2. Simulated optimal investment allocation by period

Source: Prepared by the authors

In contrast, the Unrestricted Model achieved returns closer to the IBX, but with lower volatility, which highlights the benefits of flexibility. During the pre-impeachment and the pandemic periods, the impact of exchange rates was more evident in the Unrestricted Model due to its high concentration in BDRX. Combined with fixed income, this asset generated returns up to six times higher than those of the restricted model over the same period. This finding corroborates studies that highlight the role of foreign assets in diversification and risk mitigation in unstable environments (Badaoui & Fernández, 2013; Carvalho & Sanguino, 2024).

The allocation weights shown in Figure 2 were applied to the 100,000 simulations performed using the optimization model to generate the portfolios shown in Figure 3. The results demonstrate that the Unrestricted Model provides greater diversification potential in volatile scenarios like the pandemic, achieving returns surpassing 20%. In all scenarios, the Unrestricted Model delivered better aggregate results considering higher expected returns and greater allocation potential across each eligible asset class compared to the restricted model. However, the CMN4993 Model exhibited a lower standard deviation,

reinforcing its adherence to a strategy of greater stability and prudence for institutional managers.

The need for stability and short-term liquidity in the insurance sector helps to explain why the CMN4993 Model predominantly uses conservative allocations. The insurance sector is characterized by the obligation to maintain sufficient technical and mathematical reserves to cover claims and other short-term regulatory liabilities. There is also a need for immediate liquidity to mitigate uncertain cash flows, especially during crises such as pandemics or natural disasters (Gomes & Carvalho, 2025). In this context, maintaining highly liquid, low-risk assets is crucial for fulfilling contractual obligations and preserving solvency, an aspect strictly regulated by current legislation (Carvalho & Guimarães, 2024).

In a counterfactual scenario involving insurance companies adopting alternative assets (i.e., SMLL, ISE, and GBTC), the impacts of moderately relaxing RCMN4993 were assessed. This exercise is based on the evidence presented by Flores et al. (2021b), which suggests that alternative assets can enhance diversification and increase returns in regulated portfolios.

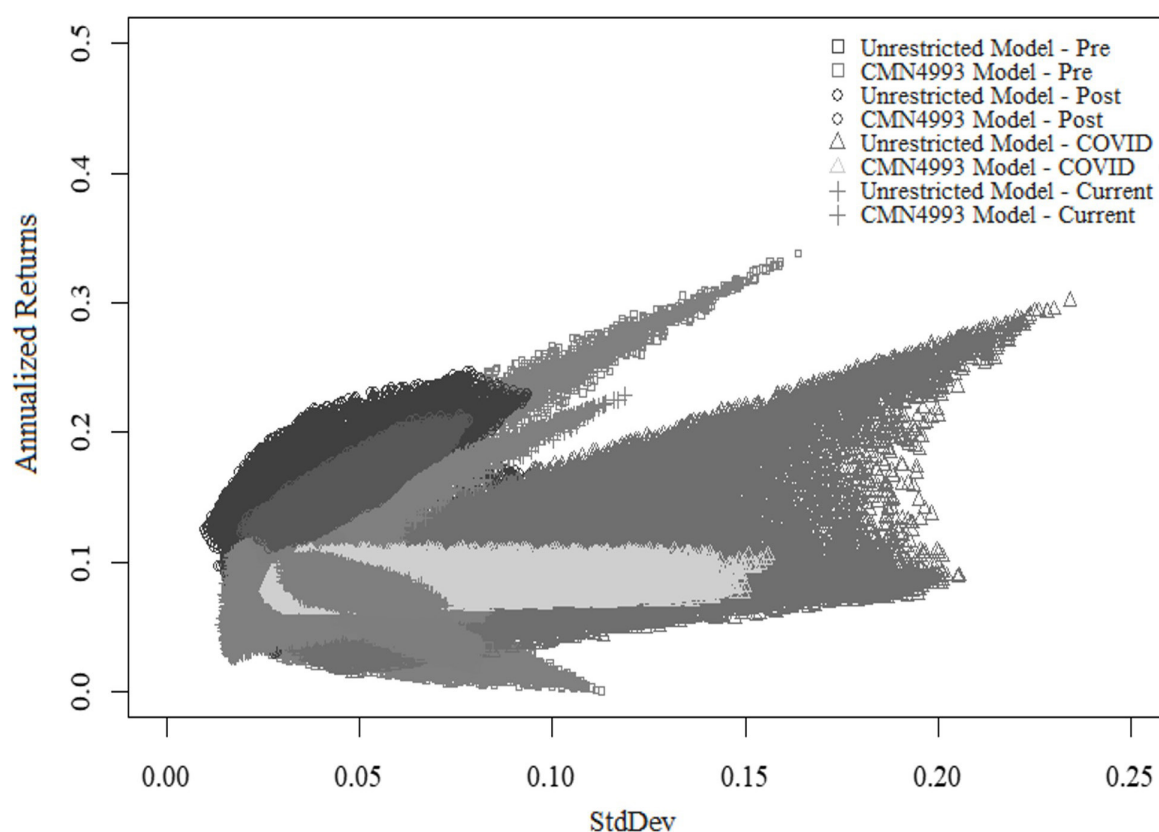


Figure 3. Simulated portfolios with and without restrictions by period

Source: Prepared by the authors

To this end, the maximum allocation percentage was tested at levels ranging from 1% to 5% (Figure 4). This range is considered conservative, given the sector's specific requirements for security, stability, and liquidity. The percentage invested in each alternative asset is presented in Table 4.

The results show that alternative assets, primarily ISE and GBTC, contributed significant gains to the efficient frontiers, increasing expected returns and improving diversification without raising volatility excessively. The lack of allocation to SMLL suggests that the model penalizes assets with unfavorable historical risk-return ratios, reflecting greater caution in the face of high volatility or pronounced loss histories.

These results support the findings of Flores et al. (2021b), who demonstrated the ability of alternative assets to optimize the performance of traditional portfolios under strict constraints, provided their loss history does not compromise future projections.

Table 5 presents a robustness analysis aimed at assessing the sensitivity of the results to the presence of GBTC. The table compares the gains in the Return/DP

ratio under optimization scenarios without flexibility ("No Alternative Assets") and with flexibility of up to 2% in alternatives, both with and without GBTC.

As expected, excluding this asset reduced some of the gains observed in the scenarios with alternatives, particularly in the pre- and post-periods when GBTC posted historically high returns. Its exclusion resulted in alternative allocations to ISE and SMLL with marginal variations relative to the normative scenario of +0.01 and -0.04, respectively. In the COVID and Current periods, however, the scenario without GBTC mirrored the normative scenario since SMLL and ISE did not yield sufficient marginal gains to justify allocation by the optimizer. When GBTC was included in the same periods, its high volatility resulted in a lower Return/DP ratio than that observed in the normative scenario. This indicates that the increase in return does not offset the increase in risk.

Nevertheless, the results suggest that sensitivity to the presence of GBTC is concentrated in periods when this asset posted historically high returns (Pre and Post), while in other periods, excluding GBTC virtually replicates the baseline scenario results.

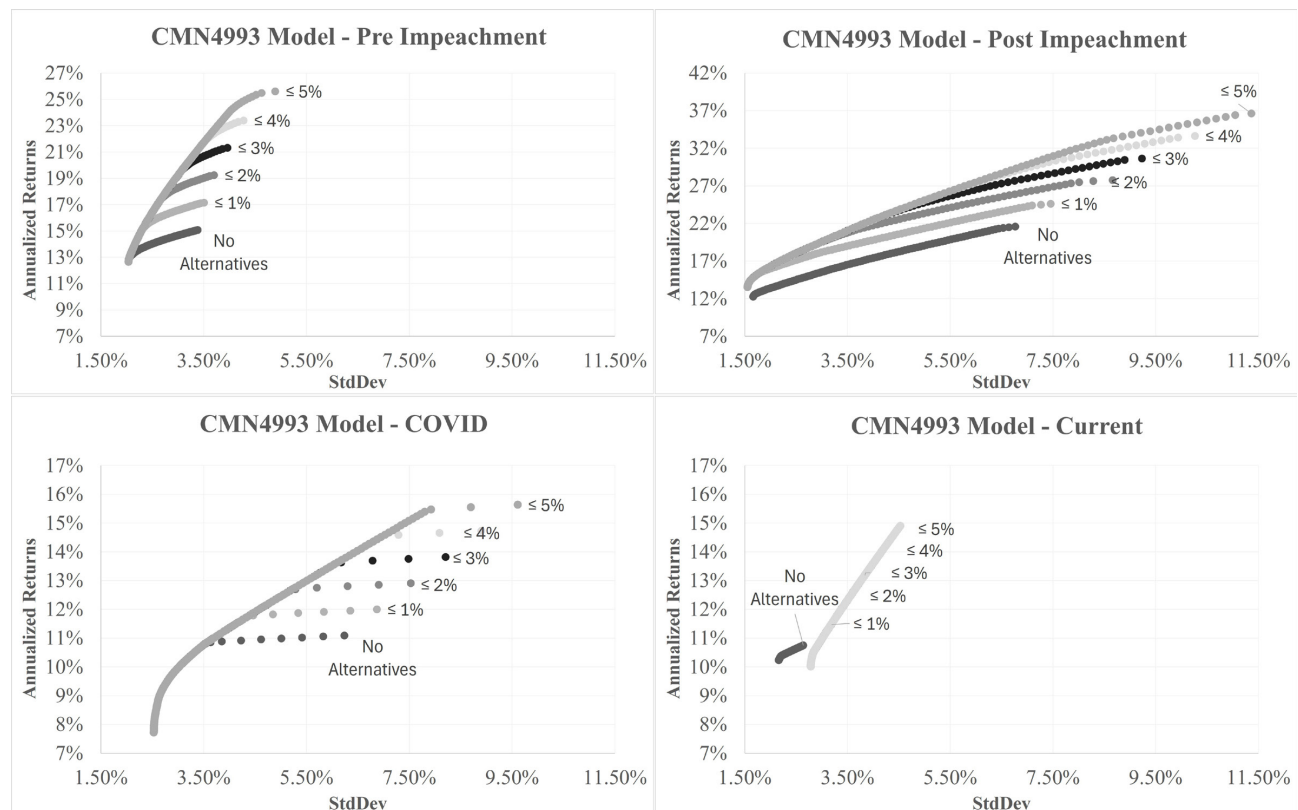


Figure 4. Impact of alternative assets: Efficient frontier before and after relaxing the 1–5% limit on alternative assets

Table 4

Percentage of optimized portfolios including each alternative asset under the relaxed efficient frontiers

	≤1%			≤2%			≤3%		
	SMLL	ISE	GBTC	SMLL	ISE	GBTC	SMLL	ISE	GBTC
Pre		2.78%	97.22%		2.50%	97.50%		24.55%	75.45%
Post			100.00%			100.00%			100.00%
COVID			100.00%			100.00%			100.00%
Current			92.11%			100.00%			100.00%
	≤4%			≤5%			Excluding GBTC (≤2%)		
	SMLL	ISE	GBTC	SMLL	ISE	GBTC	SMLL	ISE	GBTC
Pre		33.33%	66.67%		36.88%	63.12%		100.00%	
Post			100.00%			100.00%	100.00%		
COVID			100.00%			100.00%			
Current			100.00%			100.00%			

Source: Prepared by the authors.

Table 5

Robustness analysis excluding GBTC from the alternative asset universe

Period	Scenario	Average Return	Standard Deviation	Return-to-Volatility Ratio	Improvement Relative to the Portfolio Without Alternatives
Pre	No Alternative Assets	13.91%	2.53%	5.50	-
	Alternative Assets Including GBTC	15.94%	2.53%	6.30	+0.80
	Alternative Assets Excluding GBTC	13.87%	2.52%	5.51	+0.01
COVID	No Alternative Assets	9.40%	2.99%	3.14	-
	Alternative Assets Including GBTC	10.31%	3.54%	2.91	-0.23
	Alternative Assets Excluding GBTC	9.40%	2.99%	3.14	-
Post	No Alternative Assets	16.92%	3.87%	4.37	-
	Alternative Assets, Including GBTC	20.63%	3.99%	5.18	+0.80
	Alternative Assets Excluding GBTC	17.04%	3.93%	4.33	-0.04
Current	No Alternative Assets	10.31%	2.82%	3.66	-
	Alternative Assets Including GBTC	11.17%	3.09%	3.61	-0.04
	Alternative Assets Excluding GBTC	10.31%	2.82%	3.66	-

Source: Prepared by the authors.

Thus, the additional gains observed with regulatory flexibility mainly stem from including GBTC in these contexts. Conversely, excluding GBTC essentially replicates the performance observed in the scenario without alternative assets. These results should be interpreted with caution given their exploratory nature, dependence on historical time windows, and lack of allocation recommendations for alternative assets.

4.3 Results and discussion

The results suggest that the current regulatory framework based on CMN Resolution No. 4,993/2022 adopts a prudent approach by prioritizing fixed-income assets with high liquidity. While this framework addresses insurers' solvency requirements, as noted by Barucca et al. (2021)

and Carvalho and Guimarães (2024), it reduces portfolio diversification and may limit returns in low-interest-rate environments. While these restrictions are important for mitigating systemic risks, they may diminish insurers' competitiveness compared to institutions with greater regulatory flexibility.

The simulations show that even with conservative limits on alternative assets, as proposed by Flores et al. (2021b), the results are consistent with efficiency gains. There is no indication in the simulated scenarios of a deterioration in the risk-return ratio. Assets such as cryptocurrencies and sustainable funds have the potential to mitigate concentration risks and increase risk-adjusted returns, particularly during periods of high volatility, such as during the COVID-19 pandemic (Gomes & Carvalho, 2025).

This finding aligns with Cardoso et al. (2024), who observed a comparable effect in pension systems incorporating non-traditional assets into regulated portfolios. Nevertheless, the high volatility of these assets, particularly GBTC, underscores the need for careful regulatory oversight.

The effects of macroeconomic conditions also proved significant. During periods of high interest rates, portfolios concentrated in fixed income showed greater stability, in line with Ikeda and Carvalho (2022). In low-interest-rate scenarios, such as between 2020 and 2021, alternative and international assets became important for maximizing returns and diversifying risks. These findings reinforce the idea presented by Haneveld et al. (2010) and Kouwenberg and Zenios (2008) that flexibility in asset allocation is crucial for adapting strategies to economic conditions and strengthening financial resilience.

Taken together, the results suggest that aspects of regulation could be revisited, provided that prudential objectives are preserved and the sector's operational and institutional limitations are considered. Moderate relaxation combined with ALM, as discussed by Damasceno and Carvalho (2021), has the potential to increase portfolio efficiency in various macroeconomic contexts.

However, it is important to note that the results associated with the inclusion of alternative assets depend on the historical characteristics of the data and the simulated scenarios. In particular, assets such as GBTC are highly volatile and speculative, which amplifies their influence on the efficient frontier. The results suggest that the contribution of alternative assets varies by asset and period. GBTC is primarily responsible for the additional gains observed during periods of exceptional historical performance. This reinforces the idea that the potential benefits of portfolio flexibility depend on the characteristics of the assets under consideration and the market context represented by the historical windows analyzed. Thus, regulators and managers should approach the inclusion of alternative assets with caution, especially in environments of high uncertainty.

5 Final considerations

This study evaluated the effectiveness of CMN Resolution No. 4,993/2022 for managing collateral assets in the Brazilian (re)insurance sector. The study analyzed the ability of the resolution to balance stability, diversification, and financial return. The results revealed

that the current regulatory model prioritizes security and liquidity but restricts diversification and financial performance in low-interest scenarios. Conversely, the simulated introduction of alternative assets and greater regulatory flexibility suggests the potential to expand the efficient frontiers in the analyzed scenarios and increase risk-adjusted returns without compromising the risk-return ratio. These findings reinforce the importance of a regulatory framework that balances prudence and allocative efficiency.

However, the study has some limitations that should be considered when interpreting the results. First, liabilities were modeled in a simplified manner. Although inspired by the ALM framework, the model uses a more parsimonious approach, employing the solvency ratio as a proxy for the relationship between assets and liabilities. This choice aligns with the characteristics of the (re)insurance industry, where contracts are usually annual, and with the use of an aggregated approach, not based on individualized insurer data, which broadens the generalizability of the results but limits capturing the stochastic dynamics of liabilities.

Furthermore, the results may be susceptible to estimation errors and the instability characteristic of portfolio optimization models, wherein slight variations in parameters can result in substantial alterations to the solutions. Additionally, the simulated portfolios represent normative allocations that are subject to regulatory constraints but do not fully incorporate relevant operational constraints, such as asset liquidity, instrument availability, custody requirements, and governance guidelines. Therefore, the results should be interpreted as possibilities within the regulatory framework rather than as direct allocation recommendations.

This study contributes not only to the periodic review of regulatory guidelines, but also to the continuous assessment of their impact in light of changes in the macroeconomic environment and advances in risk management. Consequently, the results are conditional on the historical windows used to estimate the parameters and do not allow for a full assessment of the stability of the optimal portfolios outside the sample. Future studies could advance by incorporating macroeconomic factors into more comprehensive stochastic models and by analyzing allocation stability over time using approaches such as moving windows or out-of-sample tests. These advances are relevant for the constantly evolving market and the long-term sustainability of the insurance industry.

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SUPPLEMENTARY MATERIAL

Supplementary material accompanies this paper.

Supplementary Data 1 – Dataset

Supplementary Data 2 – Codebook

Supplementary Data 3 – R script

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