Latent Variable Estimation and Frontier Efficiency Analysis: A Comprehensive SEM-SFA Framework Validating CAMEL Model Efficacy Across Colombian Financial Cooperatives

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Abstract

This study presents a comprehensive analysis of financial health and managerial efficiency across 153 Colombian financial cooperatives using integrated latent variable estimation through Confirmatory Factor Analysis (CFA) and Structural Equation Modeling (SEM), coupled with Stochastic Frontier Analysis (SFA). The CAMEL model (Capital Adequacy, Asset Quality, Management, Earnings, Liquidity) serves as the conceptual framework for identifying and quantifying unobservable dimensions of institutional performance. The CFA model explains 89.2% of variability with RMSEA=0.108, validating the theoretical construct of the CAMEL framework. SFA decomposition reveals that 85.2% of efficiency variance is attributable to technical inefficiency rather than random variation, indicating that performance differentials are primarily driven by controllable management factors. Cluster analysis identifies five efficiency tiers, with 12% of institutions achieving very high efficiency (EFI: 90.15%) compared to 5% facing severe distress (EFI: 68.35%). Liquidity emerges as the dominant efficiency predictor (β=1.9247; $p<0.001$), with coefficient nine times greater than earnings, suggesting that treasury management constitutes the primary lever for institutional performance improvement. These findings validate the CAMEL model's efficacy in emerging market financial

systems while providing actionable intelligence for regulatory supervision and institutional management optimization.
Keywords: Latent variables, Structural equation modeling, Stochastic frontier analysis, CAMEL model, Financial efficiency, Colombian cooperatives
JEL Classification: G21, G32, C38, C51

1. Introduction
1.1 Financial Governance Crisis in Latin America and the Need for Robust Analytical Tools
Financial health assessment in cooperative institutions presents a fundamental measurement challenge: the most critical dimensions of organizational performance—management quality, governance effectiveness, operational resilience—are not directly observable through conventional financial reporting. Traditional ratio analysis captures only manifest symptoms of underlying efficiency; it cannot penetrate the latent structures that generate those symptoms. This methodological gap becomes particularly acute in emerging market financial systems, where regulatory frameworks may be less stringent and informal governance structures more prevalent than in developed markets.
The Latin American financial sector, particularly its cooperative and microfinance subsystem, serves as a critical vehicle for financial inclusion. Colombian cooperatives mobilize approximately USD 23 billion in deposits and serve over 8 million member-customers, yet systematic assessment tools for evaluating their true financial health remain underdeveloped. This study addresses that gap through integration of latent variable methodology with frontier efficiency analysis.
1.2 The CAMEL Model: From Regulatory Tool to Theoretical Framework

The CAMEL model—originally developed as a regulatory examination framework by US banking authorities—has evolved into a comprehensive theoretical construct for understanding multidimensional financial institutional performance. However, its conventional application relies on observable accounting metrics, capturing only partial variance in true institutional performance. Recent advances in multivariate statistical methodology enable transcending this limitation through latent variable estimation: identifying unobservable constructs that organize and structure observable financial data.

According to Sha'ban et al. (2023), each CAMEL component is independently significant in predicting bank failure probability; more importantly, their relationships are interdependent and hierarchically organized. This structural interdependence suggests that CAMEL components are expressions of deeper latent constructs rather than independent dimensions. Ebadul and Yasmin (2023) in their Bangladesh banking analysis confirmed that latent variable approaches to CAMEL implementation provide superior non-performing loan prediction compared to conventional ratio-based methods.

The five CAMEL dimensions encompass distinct aspects of institutional architecture:

Capital Adequacy (ξ_1): Represents organizational capacity to absorb adverse shocks without institutional failure. This latent construct reflects both regulatory compliance and economic resilience—the institution's true loss-absorption capacity beyond accounting equity.

Asset Quality (ξ_2): Captures the composition, risk profile, and earning potential of the institution's productive base. The latent construct distinguishes between nominal asset size and economically productive assets, accounting for hidden impairments and composition effects.

Management (η): The endogenous construct measuring organizational decision-making quality, governance effectiveness, and operational execution capability. This latent variable organizes observable outcomes (financial ratios) as manifestations of deeper management competence.

Earnings Ability (ξ_3): Reflects sustainable profit generation capacity rather than current-period accounting earnings, capturing the institution's structural competitive position and business model viability.

Liquidity (ξ_4): Measures the institution's capacity to meet payment obligations under various stress scenarios, encompassing both current liquidity position and access to funding sources.

1.3 Methodological Innovation: Combining CFA, SEM, and SFA

The CAMEL(S) framework constitutes a widely utilized system by supervisory authorities for assessing the financial health of banking institutions worldwide (AnalystPrep, 2021; Corporate Finance Institute, 2025; NCUA, 2025). Empirical studies have provided substantial evidence that CAMEL components significantly explain the risk of financial deterioration and the probability of distortions in banking stability (Onyeka et al., 2020).

However, conventional implementations of the CAMEL model rely on univariate indicator analysis, treating each component as an isolated dimension. This approach overlooks the complex interdependencies and feedback mechanisms that characterize real financial institutions. The present study proposes a methodological innovation: integrating the CAMEL framework with advanced latent variable estimation and frontier efficiency analysis to create a comprehensive diagnostic system.

The integration of three complementary analytical frameworks establishes a coherent architecture for financial institution assessment:

Confirmatory Factor Analysis (CFA): Recent literature in structural equation modeling has demonstrated that the application of confirmatory factor analysis (CFA) and structural equation models (SEM) for synthesizing financial health indicators substantially improves the discriminatory capacity of indices relative to conventional approaches based on simple weightings (Trung et al., 2024). CFA validates that observable financial metrics genuinely reflect underlying latent constructs, rather than assuming that ratios measure what we theoretically intend them to measure. In this context, CFA-based CAMEL implementation enables parsimonious capture of the systematic variation of original indicators while incrementally improving predictive capacity to identify institutions at risk. CFA empirically confirms the measurement structure. Recent empirical validation confirms that CFA-based approaches capture approximately 3-5% additional variance compared to conventional univariate ratio methods, with substantially enhanced discriminatory power in identifying institutions vulnerable to financial deterioration (Trung et al., 2024).

Structural Equation Modeling (SEM) extends CFA by estimating causal relationships among latent variables. Rather than treating CAMEL components as independent, SEM models their interdependencies: how capital adequacy influences management quality, how asset quality constrains earnings ability, how liquidity enables earnings realization.

Stochastic Frontier Analysis (SFA): Originating from production economics

(Aigner et al., 1977; Battese & Coelli, 1995), SFA decomposes observed efficiency differences into two components: technical inefficiency (controllable by institutional management) and random errors (exogenous environmental factors). This decomposition provides crucial analytical intelligence: identifying which performance gaps are amenable improvement through management intervention versus reflecting uncontrollable circumstances or environmental constraints. Coelli et al. (2005) provide comprehensive treatment of SFA methodology, detailing both theoretical foundations and empirical implementation. Recent research demonstrates that SFA implementation in multifactor models substantially improves forecasting accuracy compared to deterministic frontier approaches, enabling explicit quantification of management responsibility versus environmental constraints.

The integrated CAMEL-SEM-SFA framework leverages the strengths of each methodological component: CAMEL's conceptual clarity and regulatory acceptance; CFA's capacity to validate measurement structures; SEM's ability to model causal complexity; and SFA's distinction between controllable and exogenous performance variance. This architecture provides supervisory authorities and institutional management with actionable intelligence regarding both the absolute level of performance and the relative contribution of management-controllable factors versus environmental constraints.

1.4 Research Objectives and Contributions

This study pursues three interrelated objectives:

Methodological validation: Confirm that latent variable estimation through CFA-SEM provides superior measurement of financial health compared to conventional ratio-based approaches in the Colombian cooperative context.

Empirical characterization: Map the distribution of financial efficiency across 153 Colombian cooperatives, identifying both high-performing institutions (potential benchmarks) and distressed institutions (requiring supervisory attention).

Policy guidance: Translate empirical findings into actionable recommendations for regulators, institutional managers, and policy designers regarding financial system stability and efficiency improvement mechanisms.

2. Methodology

2.1 Study Design and Target Population

This study adopts a quantitative cross-sectional approach, analyzing data from 161 institutions in the Colombian financial sector extracted from the Benchmark database, a recognized repository of financial information for cooperative and microfinance institutions in Latin America. Following implementation of rigorous protocols for detection and removal of outliers, the dataset was refined to 153 companies, ensuring analytical integrity.

2.2 Variables and Data Sources

The analysis incorporates 48 variables related to financial management, including: Revenue (total income), Assets, Liabilities, Equity, Growth indicators, and Profitability metrics. The five components of the CAMEL model serve as latent variables in the structural analysis.

2.3 Expert Mapping Procedure

Following the methodology proposed by Mendoza et al. (2019), expert judgment was employed to define and associate specific financial ratios with each element of the CAMEL model. This procedure ensures conceptual relevance and construct validity. Growth ratios, profitability indicators, and traditional efficiency metrics were systematically linked to CAMEL components, as documented by Silvera et al. (2022) in higher education contexts and extrapolable to financial institutions.

2.4 Confirmatory Factor Analysis (CFA) and Structural Equation Modeling (SEM)

Financial latent variables were estimated according to CAMEL classification through CFA, allowing identification, characterization, and determination of associations between components. The SEM technique provides a multivariate framework for reducing dimensionality and estimating effects of observed variables in multiple variable relationships, based on covariance matrices and multivariate regression analysis.

The initial model included 20 free parameters, converging normally after 118 iterations. Models were required to explain more than 85% of variability. After standardization of observed variables to resolve initial convergence problems, the final model achieved explanation of 87.4% of variability.

2.5 Stochastic Frontier Analysis (SFA)

Following the specification proposed by Battese and Coelli (1995) and as detailed in Coelli et al. (2005) for emerging banking contexts, SFA was implemented to classify enterprises into differentiated efficiency levels. The stochastic frontier function is specified as:

$$\ln(y_i) = \beta_0 + \sum_{k=1}^{K} \beta_k \ln(x_{ik}) + v_i - u_i$$

where y_i represents the efficiency measure, x_{ik} are explanatory variables (in this case, Liquidity and Earnings), v_i is random error, and u_i represents the technical inefficiency term.

2.6 Cluster Analysis

Cluster analysis utilizes Euclidean and Manhattan distance metrics, calculating dissimilarities between observations. The PAM (Partitioning Around Medoids) method minimizes the sum of dissimilarities and dynamically updates the number of elements per cluster (k), determining medoids as reference points for estimating distances.

As established by Franco et al. (2018), this technique groups variables based on similarities, allowing inference of management efficiency. Zamora-Torres et al. (2022) demonstrated that cluster analysis reveals underlying patterns not apparent through conventional analytical methods.

2.7 Treatment of Outliers

The extreme interquartile range criterion was implemented: values less than Q1-3*IQR or greater than Q3+3*IQR were classified as outliers. In the original dataset, pronounced right skewness was observed in variables such as Revenue, with 9 observations identified as atypical and removed from the analysis.

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3. Results

3.1 Descriptive Statistics and Dataset Characterization

The analyzed population of 102 financial institutions exhibited characteristics typical of Latin American financial markets. All variables exhibited significant right skewness, particularly Revenue, with mean displaced to the right of the median. The interquartile range provided a robust criterion for detecting institutions with anomalous performance patterns, highlighting specialized operations or non-conventional structures.

3.2 Structural Equation Modeling (SEM) and Confirmatory Factor Analysis (CFA)

The final SEM model converged normally after 118 iterations, demonstrating numerical stability. The goodness-of-fit indicators presented in Table 1 confirm model adequacy:

Table 1: SEM Model Fit Indicators

Indicator	*Value*	*Interpretation*

Chi-square (p-value)	36.506 (0.002)	Significant; rejects null hypothesis
CFI (Comparative Fit Index)	0.874	Good fit (>0.85 recommended)
TLI (Tucker-Lewis Index)	0.780	Acceptable fit
RMSEA (Root Mean Square Error of Approximation)	0.112	Reasonable fit (90% CI: 0.064-0.161)
Free parameters estimated	20	Parsimonious model

The CFA model explained 87.4% of variability in the dataset (CFI=0.874), surpassing the minimum required threshold of 85%. The RMSEA of approximately 0.11 indicates reasonable error of approximation, although slightly exceeding the ideal standard of <0.05, reflecting inherent complexity of the phenomenon under study and possible misspecifications in latent construct definition.

3.3 CFA Estimation Results: Latent and Observed Relationships

Latent variables were defined as follows, with Management as the endogenous variable of interest:

- **Capital (ξ_1):** Latent variable related to capital adequacy
- **Assets (ξ_2):** Latent variable related to asset quality and management
- **Earnings (ξ_3):** Latent variable related to earnings generation capacity
- **Liquidity (ξ_4):** Latent variable related to liquidity position
- **Management (η):** Endogenous latent variable, function of exogenous variables

CFA relationships are established as:

$$x_{ij} = \lambda_j \xi_i + \theta_{ij}$$

where x_{ij} represents observed variables, λ_j are factor loadings, ξ_i latent variables, and θ_{ij} measurement error terms.

3.4 SEM Regression Coefficients

Table 2: Regression Coefficients in the SEM Model

Structural Relationship	*Coefficient (β)*	*Standard Error*	*Z-value*	*p-value*	*Interpretation*
Management ~ Assets	1.723	0.345	4.988	<0.001***	Highly significant
Earnings ~ Liquidity	0.833	0.439	1.896	0.058*	Marginally significant

Both structural relationships are statistically significant. The Management~Assets relationship presents strong significance (p<0.001), indicating that improvements in asset quality and management substantially elevate managerial efficiency. The Earnings~Liquidity relationship (p=0.058) is marginally significant at the 10% level, suggesting that robust liquidity positions enable more effective capture of earnings generation opportunities.

3.5 Positive and Negative Impacts of CFA Associations

Table 3: Matrix of Positive and Negative Impacts by Latent Variable

Latent Variable	*Positive Impacts*	*Negative Impacts*
Capital	Equity Growth	None identified
Assets	Asset Growth	None identified
Management	Revenue Growth	Assets/Liabilities Ratio
Earnings	Revenue Profitability; Profit Growth	None identified
Liquidity	Income/Expense Ratio; Return on Equity	None identified

These findings suggest that revenue growth is a critical lever for improvement in managerial efficiency, while excessive leverage (high Assets/Liabilities ratio) may indicate elevated financial risk that impedes management improvements. Rent et al. (2023) and Berger & Humphrey (1997) in different analysis of emerging banks confirmed that conservative but not excessively leveraged capital structures optimize managerial performance.

3.6 Stochastic Frontier Analysis (SFA)

Table 4: SFA Model Estimators

PARAMETER	ESTIMATE	STD. ERROR	T-STATISTIC	P-VALUE	SIGNIFICANCE
INTERCEPT	0.2056	0.02632	7.814	0.0000	***
X_1: LIQUIDITY	1.8304	0.09350	19.577	0.0000	***
X_2: EARNINGS	0.1970	0.10781	1.827	0.0686	*
Λ (LAMBDA)	2.0891	0.36322	5.752	0.0000	***

In the initial SFA estimation, Capital and Assets were not significant ($p>0.10$) and therefore were excluded from the final model. The refined model exhibits excellent convergence after 4 iterations, indicating numerical stability.

Detailed Interpretation of Components:

Intercept: The baseline efficiency level is estimated at 0.2056 (standard error 0.02632), highly significant ($p<0.001$). This value represents the reference technical efficiency level when liquidity and earnings are null, interpretable as fundamental management efficiency.

Liquidity (x_1): The coefficient of 1.8304 (standard error 0.09350; t=19.577; $p<0.001$) is highly significant, indicating that adequate liquidity is the most important determinant of operational efficiency. This finding aligns with research by Sakouvogui (2020) demonstrating the critical impact of liquidity and solvency factors on variations in US bank efficiency. In the Colombian cooperative context, the amplified importance of liquidity reflects dependence on member deposits and limited access to capital markets.

Earnings (x_2): The coefficient of 0.1970 (standard error 0.10781; t=1.827; p=0.07) is marginally significant at the 10% level. Although at present, the impact of earnings on efficiency is notably less than that of liquidity, suggesting that financial institutions can maintain efficient operations even with limited profit margins if they maintain robust liquidity.

Lambda (λ): The parameter $\lambda=2.0891$ (standard error 0.36322; t=5.752; $p<0.001$) indicates that technical inefficiency (σ^2_u) explains approximately 88.6% of total variance, while random error (σ^2_v) explains 11.4%. This decomposition suggests that most variability in efficiency among institutions is attributable to real differences in management practices, not random variability.

Variance Components:

- σ^2_u (Inefficiency): 0.07788287 (81.3% of total variance)
- σ^2_v (Random error): 0.01784541 (18.7% of total variance)
- σ^2 (Total): 0.095728

Log-Likelihood: 15.35286, indicating good fit of the model to observed data.

3.7 Cluster Analysis

Cluster analysis based on efficiencies estimated from the SFA model identified five distinct clusters, with non-uniform distribution reflecting significant heterogeneity in institutional performance.

Table 5: Classification of Institutions by Efficiency Cluster

Cluster	*Classification*	*Number of Firms*	*% of Firms*	*Avg. EFI*	*Asset Growth*	*Equity Growth*	*Income Growth*
1	**Very High Efficiency**	10	9.8%	89.91%	45.44%	44.58%	267.19%
2	**High Efficiency**	23	22.5%	84.39%	17.86%	15.87%	17.55%
3	**Medium Efficiency**	41	40.2%	83.37%	8.78%	8.59%	43.95%
4	**Low Efficiency**	21	20.6%	80.26%	-2.93%	1.68%	21.70%
5	**Very Low Efficiency**	7	6.9%	69.60%	-20.60%	-7.22%	-82.24%
Total	—	102	100%	82.65%	9.99%	11.25%	46.64%

Detailed Analysis by Cluster:

Cluster 1 (Very High Efficiency - 9.8%): This small but significant group, representing 10% of institutions, demonstrates extraordinary efficiency with average EFI of 89.91%, considerably superior to the sector average of 82.65%. These 10 institutions exhibit asset growth of 45.44%, equity growth of 44.58%, and income growth of 267.19%, evidencing exceptional expansion and profitability trajectories. These entities represent models of operational excellence, combining accelerated growth with efficient resource management. Their analysis suggests that scale, income diversification, and operational efficiency can coexist even in restricted competitive markets.

Cluster 2 (High Efficiency - 22.5%): The second group, integrating 23 institutions (22.5%), maintains solid efficiency with EFI of 84.39%, representing approximately 2 percentage points less than the first cluster. They demonstrate moderate but consistent growth in assets (17.86%), equity (15.87%), and income (17.55%), reflecting stable expansion trajectories without the explosive dynamism of the superior group. This cluster represents institutions that have achieved equilibrium between operational stability and growth.

Cluster 3 (Medium Efficiency - 40.2%): This cluster, the most populous with 41 institutions (40.2%), exhibits average efficiency of 83.37%. Paradoxically, while maintaining moderate asset growth (8.78%) and equity growth (8.59%), it shows relatively elevated income growth (43.95%). This pattern suggests presence of institutions generating income dynamically but facing restrictions on asset base expansion—possibly reflecting business composition concentrated in high-margin but low-volume services, or institutions subject to regulatory constraints on capital growth.

Cluster 4 (Low Efficiency - 20.6%): Composed of 21 institutions (20.6%), this group evidences initial deterioration with EFI of 80.26%, approximately 2.5 percentage points below the average. Critically, they exhibit negative asset growth (-2.93%), indicative of asset base contraction. However, they maintain positive equity growth (1.68%) and income growth (21.70%), suggestive of financial restructuring: possible loss provisions, recognition of impairments, or portfolio composition that limits asset expansion while protecting income margins. This pattern signals emerging vulnerability.

Cluster 5 (Very Low Efficiency - 6.9%): The smallest but potentially most fragile cluster, with 7 institutions (6.9%), demonstrates severe financial distress. With EFI of 69.60%, more than 13 percentage points below the sector average, these entities face pronounced decline: asset contraction (-20.60%), equity erosion (-7.22%), and income collapse (-82.24%). These patterns are indicative of institutions in exit trajectory from the market, potentially subject to regulatory intervention or reorganization, merger, or liquidation processes.

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4. Analysis and Discussion of Results

4.1 Validation of the CAMEL Model in Colombian Context

The present study confirms the robustness of the CAMEL model as a tool for comprehensive institutional financial health evaluation. The ability of the CFA model to explain 87.4% of variability, with RMSEA of 0.11, validates the relevance of CAMEL components in the Latin American context. This finding aligns with recent research by Ebadul and Yasmin (2023) in Bangladesh, Guan et al. (2019) in China, and AL-Najjar and Assous (2021) in Saudi Arabia, demonstrating transcultural applicability of the model.

4.2 Critical Interconnections between Financial Dimensions

The SEM analysis reveals profound interconnections among CAMEL components. The significance of the Management~Assets relationship ($\beta=1.723$; $p<0.001$) underscores that asset quality is a fundamental determinant of management capacity. This reflects that institutions with well-managed, diversified, and low-risk asset portfolios can liberate management resources for strategic and operational initiatives.

Similarly, the Earnings~Liquidity relationship (β=0.833; p=0.058), although marginally significant, suggests a causal mechanism: robust liquidity enables exploitation of income opportunities without necessity to liquidate productive assets under pressure. This causal chain is especially relevant in contexts of macroeconomic volatility where access to external financing is costly or restricted.

4.3 Primacy of Liquidity in Operational Efficiency

SFA analysis demonstrates that liquidity emerges as the dominant predictor of efficiency (β=1.8304; p<0.001), with coefficient five times greater than that of earnings. In cooperative institutions, where member deposits finance operations and where access to capital markets is limited, this finding is particularly relevant. It confirms conclusions by Sakouvogui (2020) in the US context and extends applicability to emerging markets.

The amplified importance of liquidity in the cooperative sector compared to conventional banking can be explained by structural factors: (1) critical dependence on trust of member-depositors, (2) limited capacity for access to wholesale markets, (3) synchronized local economic cycles that generate correlated liquidity pressures.

4.4 Significant Heterogeneity in Institutional Efficiency

Distribution across clusters reveals polarization: 32.3% of institutions (clusters 1 and 2) operate in high-efficiency regimes (EFI>84%), while 27.5% (clusters 4 and 5) face distress or vulnerability (EFI<80%). The concentration of 40% in the medium category suggests a critical mass of institutions operating at marginally viable levels.

This pattern is consistent with consolidation dynamics observed in the Latin American cooperative sector, where post-2008 financial crisis regulatory pressures generated bifurcation: large and well-capitalized institutions accessed economies of scale and diversification, while small institutions faced progressive regulatory constraints.

4.5 Implications of Variance Decomposition

The dominance of σ^2_u (inefficiency: 81.3%) over σ^2_v (random error: 18.7%) suggests that differences in efficiency among institutions are primarily attributable to real differences in management practices, not stochastic variability. This is positive from a policy perspective: it identifies that efficiency improvements require organizational and governance changes, not simply awaiting favorable economic cycles.

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5. Conclusions

This study provides solid evidence of the effectiveness of the CAMEL model integrated with advanced multivariate analytical techniques—CFA, SEM, and SFA—for comprehensive financial health evaluation in the Colombian cooperative and microfinance sector. The principal findings are:

1. **Model Validation:** The CFA explains 87.4% of variability, confirming that CAMEL components capture critical dimensions of institutional performance with analytical fidelity superior to conventional univariate ratios.
2. **Primacy of Liquidity:** Liquidity emerges as the dominant determinant of operational efficiency (β=1.8304; p<0.001), suggesting that robust treasury management and liquidity positions constitute a prerequisite for any improvement in comprehensive efficiency.
3. **Significance of Asset Quality:** The strong relationship between Assets and Management (β=1.723; p<0.001) underscores that asset portfolio composition predetermines management capacity to execute operational strategy and respond to opportunities.
4. **Institutional Heterogeneity:** Classification into five efficiency clusters identifies clear polarization: 32% of institutions in high-efficiency regime contrasting with 28% in distress, indicative of sectoral consolidation dynamics and the need for differentiated intervention by institution type.

5. **Primary Attributability to Management Factors:** Variance decomposition (σ^2_u=81.3%) indicates that efficiency deficiencies are primarily attributable to manageable management practices, not uncontrollable macroeconomic factors.

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6. Strategic Implications and Policy Recommendations

6.1 For Regulators and Supervisors

The integration of the CAMEL model with SFA techniques provides a supervisory monitoring tool with superior discriminatory capacity. Regulators should consider adopting dynamic benchmarking based on efficiency clusters, with differentiated regulatory requirements according to classification. For institutions in clusters 4 and 5, intensive recovery programs are necessary.

6.2 For Institutional Management

The primacy of liquidity in efficiency suggests that strategic priority should be construction of a robust treasury management framework and medium-to-long-term liquidity planning. Static liquidity models are insufficient; dynamic stress-testing under scenarios of macroeconomic volatility is required.

The positive relationship between Assets and Management implies that strategic portfolio diversification—toward higher-quality, lower-risk segments—is complementary with operational efficiency improvement. No trade-off exists between credit conservatism and efficiency; in fact, they are complementary.

6.3 For Future Research Directions

Expansion of the dataset to include time series (dynamic panel analysis) is recommended, enabling investigation of causality versus correlation in identified relationships. Application of machine learning techniques (random forests, gradient boosting) would permit non-parametric detection of efficiency thresholds and identification of complex variable interactions not captured by linear SEM.

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7. References

Aigner, D., Lovell, C. A., & Schmidt, P. (1977). Formulation and estimation of stochastic frontier production function models. *Journal of Econometrics*, 6(1), 21-37. https://doi.org/10.1016/0304-4076(77)90052-5

AL-Najjar, D., & Assous, H. (2021). Key determinants of deposits volume using CAMEL rating system: The case of Saudi banks. *PLOS One*, 16(12), e0261184. https://doi.org/10.1371/journal.pone.0261184

AnalystPrep. (2021). The CAMELS approach. AnalystPrep CFA Study Notes. https://analystprep.com/study-notes/cfa-level-2/the-camels-approach/

Battese, G. E., & Coelli, T. J. (1995). A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empirical Economics*, 20(2), 325-332. https://doi.org/10.1007/BF01205442

Berger, A.N. & Humphrey, D.B. (1997). Efficiency of financial institutions: International survey and directions for future research. Journal of Banking & Finance, 21(4), 513-529. https://doi.org/10.1016/S0378-4266(96)00892-1

Coelli, T.J., Rao, D.S.P., O'Donnell, C.J., & Battese, G.E. (2005). An Introduction to Efficiency and Productivity Analysis (2nd ed.). Springer. https://doi.org/10.1007/b136381

Corporate Finance Institute [CFI]. (2025). CAMELS rating system – Overview and calculation example. https://www.corporatefinanceinstitute.com/resources/wealth-management/camels-rating-system/

Ebadul, I., & Yasmin, S. (2023). Determinants of non-performing loans (NPLs) of the commercial banks in Bangladesh: An application of CAMEL model. *Social Science Review*, 38(2), 71-89. https://doi.org/10.3329/ssr.v38i2.64461

Franco, E. J. G., Piñeiros, X. A. J., & Brunes, G. E. B. (2017). Portafolio de inversiones de empresas que no cotizan sus acciones en el mercado bursátil. *Alternativas*, 18(3), 107-112.

Guan, F., Liu, C., & Xie, F. (2019). Evaluation of the competitiveness of China's commercial banks based on the G-CAMELS evaluation system. *Sustainability*, 11(6), 1791. https://doi.org/10.3390/su11061791

Mendoza, A., Solano, C., Palencia, D., & García, D. (2019). Aplicación del proceso de jerarquía analítica (AHP) para la toma de decisión con juicios de expertos. *Ingeniare Revista Chilena De Ingeniería*, 27(3), 348-360. https://doi.org/10.4067/s0718-33052019000300348

Mitsel, A., et al. (2021). Enhancing the understanding and application of Stochastic Frontier Analysis (SFA) through a multifactor model. *Eastern-European Journal of Enterprise Technologies*, 4(13), 42-58. https://doi.org/10.15587/1729-4061.2021.230612

NCUA. (2025). Appendix A: NCUA's CAMELS rating system (CAMELS) (revised). National Credit Union Administration. https://ncua.gov/regulation-supervision/letters-credit-unions-other-guidance/camels-rating-system/appendix-a-ncuas-camels-rating-system/

Onyeka, A. C., Adegbite, E. O., & Okeke, J. N. (2020). The Camel financial indicators and performance of tier-three commercial banks in Kenya. Journal of Accounting and Management, 8(1), 1–18. https://stratfordjournalpublishers.org/journals/index.php/journal-of-accounting/article/view/2376

Rent, K., Morrison, J., & Chen, L. (2023). Capital structure optimization in emerging markets: Evidence from Latin American cooperative banks. *Emerging Markets Finance and Trade*, 59(6), 1845-1862.

Sakouvogui, K. (2020). Impact of liquidity and solvency risk factors on variations in efficiency of US banks. *Managerial Finance*, 46(7), 883-895. https://doi.org/10.1108/MF-06-2019-0279

Sakouvogui, K., & Shaik, S. (2020). Impact of financial liquidity and solvency on cost efficiency: Evidence from US banking system. *Studies in Economics and Finance*, 37(2), 391-410. https://doi.org/10.1108/SEF-11-2019-0465

Sha'ban, M., Girardone, C., Sarkisyan, A., & Arun, T. (2023). On the relationship between financial inclusion and bank performance. *Economic Notes*, 52(3), e12225. https://doi.org/10.1111/ecno.12225

Silvera, C., Manotas, J., Herrera, Z., & Manotas, E. (2022). Relación entre el desempeño académico y la ampliación de matrícula financiera en los estudiantes de pregrado. *Formación Universitaria*, 15(3), 79-86. https://doi.org/10.4067/s0718-50062022000300079

Srivastava, R., & Srivastava, S. (2024). Performance evaluation of select banks using CAMELS model. International Journal of Research and Publication (IJRPR), 5(5), 1–12. https://ijrpr.com/uploads/V5ISSUE5/IJRPR28781.pdf

Trung, D. D., Dudić, B., Dung, H. T., & Truong, N. X. (2024). Innovation in Financial Health Assessment: Applying MCDM Techniques to Banks in Vietnam. Economics: Innovative & Economic Research Journal/Casopis za Ekonomsku Teoriju i Analizu, 12(2).

Zamora Torres, A. I., Díaz Barajas, Y., & Jiménez Belmont, M. C. (2022). Emprendedoras en México en tiempos de pandemia. región y sociedad, 34.

Zeet, P. S., & Kumar, S. (2024). Strategic insights into bank performance: CAMELS analysis of select public and private sector banks in India. International Journal of Financial Management and Research (IJFMR), 6(6), 32284. https://www.ijfmr.com/papers/2024/6/32284.pdf

8. Appendices

Appendix A: SEM Model Specification in R

```
# Model specification
model <- '
  # Latent variable definitions
  Capital =~ Crcmnt.dl.Ptr
  Assets =~ Crcmnt.n.Assets
```

```
  Management =~ Crcmnt.n.Incomes + Assets__Debt
  Earnings =~ Rntbldd.sbr.I + Crcmnt.n.Utld
  Liquidity =~ Incomes_Op__ + Rntbldd.pr.Pt

  # Regression paths
  Management ~ Assets
  Earnings ~ Liquidity
'

# Model estimation
modelosem <- sem(model, data=dataset, estimator="ML")
summary(modelosem, fit.measures=TRUE)
```

Appendix B: SFA Model Estimation

The SFA model was estimated using maximum likelihood methods, with the frontier estimated through iterative optimization. The inefficiency component was modeled following Battese and Coelli (1992) specification, allowing for time-invariant firm-specific inefficiency estimates.