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Hybrid Bayesian and Machine Learning for Profitability Prediction in LQ45 Firms

Junita Silele[1], Maylen Kambuaya[1], Hesty Theresia Salle[1], Ulfah Muslimin[1], Annisa Fitriah Mudassir[1], Bill Pangayow[1*]
[1]Cenderawasih University, Jl. Kamp Wolker, Yabansai, Heram, Jayapura City, Papua 99224, Indonesia
*Corresponding Email: billpangayow@feb.uncen.ac.id

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ABSTRACT

Understanding the drivers of firm profitability is essential for companies in emerging markets, where structural uncertainties and competitive pressures often shape financial performance. This study investigates how four core financial ratios: current ratio (CR), debt-to-asset ratio (DAR), net profit margin (NPM), and total asset turnover (TATO), influence return on assets (ROA) among LQ45 firms listed on the Indonesia Stock Exchange (IDX) from 2020 to 2023. Using 80 firm-year observations, the analysis applies a hybrid approach combining Bayesian regression, which captures parameter uncertainty, with XGBoost-SHAP to enhance interpretability and detect nonlinear patterns. The Bayesian posterior estimates indicate that TATO has the strongest effect on profitability (β = 0.072, 95% CI: 0.041–0.101), while DAR shows a moderate positive influence (β = 0.018, 95% CI: 0.005–0.032). NPM demonstrates a weaker but still positive contribution (β = 0.009, 95% CI: 0.001–0.018), whereas CR exhibits a non-significant effect (β = –0.002, 95% CI: –0.010–0.006). Numerically, a 10% increase in TATO corresponds to an estimated 0.7% rise in ROA, underscoring the central role of operational efficiency in shaping firm profitability. These findings reinforce the Resource-Based View and Trade-Off Theory and highlight the value of hybrid analytical frameworks for improving the interpretability and robustness of profitability models in emerging markets.

Keywords: Bayesian Regression; Financial Performance; Profitability Determinants; SHAP Analysis; Total Asset Turnover

INTRODUCTION

Profitability ratios, especially return on assets (ROA), are widely used to assess how effectively firms convert their resources into returns; a key indicator of financial health and operational efficiency in contemporary research (Fadillah et al., 2024; Ramdhan et al., 2025). In emerging markets like Indonesia, where economic structures and corporate governance frameworks significantly diverge from those of developed economies, comprehending the factors that influence profitability is essential for investors, policymakers, and managers (Gooy et al, 2021; Gunadi et al., 2024; Gunawan et al., 2022; Susan et al., 2022). Companies included in the LQ45 index of the Indonesia Stock Exchange (IDX) are characterized by their liquidity and high market capitalization, positioning them as a significant subject for examining the impact of financial ratios on corporate performance.

Financial ratios remain essential analytical tools for evaluating corporate performance because they capture critical aspects of liquidity, leverage, efficiency, and profitability. Recent empirical studies reinforce the importance of these ratios in explaining firm outcomes. For instance, liquidity indicators such as the current ratio (CR) have been shown to play a decisive role in determining corporate stability and long-term financial viability, where weaker liquidity positions significantly increase the likelihood of financial distress (Li, 2024; Rialdy & Fauzan, 2024). Complementing this view, emerging-market evidence demonstrates that both liquidity and solvency ratios significantly influence profitability and overall financial performance, suggesting that firms with stronger short-term financial structures tend to achieve better operational outcomes (Fikri & Yolanda, 2023). Beyond liquidity and solvency, firm-specific financial characteristics, such as capital structure choices and asset utilization, have also been identified as key determinants of performance, with leverage and efficiency metrics shaping profitability outcomes differently across industries (Msomi & Nzama, 2023). Collectively, this evidence highlights that financial ratios function not merely as descriptive indicators but as strategic determinants of firm performance across diverse economic environments.

Conventional empirical methods, including ordinary least squares (OLS) and panel regression models, typically estimate the average impact of financial ratios on profitability and other performance indicators (Aldboush et al., 2023; Berliana et al., 2024). Although these approaches remain the workhorse of empirical research, they have at least two important limitations. First, mean-based specifications tend to mask firm-level heterogeneity and non-linear patterns in the way liquidity, leverage, and efficiency ratios translate into profitability. Second, classical regression frameworks provide point estimates and confidence intervals but do not offer full probabilistic interpretations of the parameters, which can be problematic in small samples or in the presence of model uncertainty. In response to these limitations, recent studies in accounting and finance increasingly integrate machine learning (ML) techniques, such as random forests and gradient boosting, to exploit their superior predictive capabilities while still relying on traditional ratio-based inputs (Feng et al., 2025). However, the widespread criticism that many ML models operate as “black boxes” has led to a growing demand for methods that combine rigorous statistical inference with interpretable prediction, motivating the use of Bayesian regression and explainable ML tools in profitability analysis.

Bayesian regression in financial research provides a probabilistic framework that estimates full posterior distributions and credible intervals for model parameters, thereby strengthening inference on the effects of financial ratios on profitability, particularly in small-sample settings. Empirical studies on working capital management, bank capital structure, and liquidity indicate that Bayesian linear regression effectively captures parameter uncertainty when analyzing the impact of leverage, liquidity, firm size, and

operational efficiency on profitability indicators such as ROA, return on equity (ROE), and net interest margin (NIM) (Kong et al., 2023; Oanh et al., 2023). In parallel, recent credit risk and credit scoring studies show that financial risk models based on Extreme Gradient Boosting (XGBoost), optimized via Bayesian hyperparameter search and explained using SHapley Additive exPlanations (SHAP), achieve high predictive accuracy while remaining interpretable, because SHAP decomposes each prediction into feature-level contributions of financial ratios and other risk indicators. Taken together, these findings support a hybrid framework that combines Bayesian regression for robust probabilistic inference with XGBoost–SHAP for accurate and interpretable prediction, closely aligning with the approach applied to LQ45 firms' profitability analysis (Lundberg et al., 2020; Shoko et al., 2025; Vehtari et al., 2024).

Despite the extensive research on financial ratios and profitability, three gaps persist. First, most studies rely on mean-based approaches and fail to account for heterogeneity in firm characteristics. Second, limited research applies interpretable ML techniques to profitability analysis, especially in emerging markets. Third, the integration of Bayesian inference and explainable AI in financial performance research remains underexplored. Recent studies also indicate that environmental, social, and governance (ESG) policies can indirectly influence financial performance by improving operational resilience and efficiency (Klimova, 2022).

This study addresses the limited methodological diversity and the lack of integrated analytical approaches in prior profitability research by combining Bayesian regression with XGBoost-SHAP to examine how the CR, debt-to-asset ratio (DAR), net profit margin (NPM), and total asset turnover (TATO) influence ROA among LQ45 firms in Indonesia (Bussmann et al., 2025; Çankal & Ever, 2025; Li & Liu, 2025). The main objective is to evaluate the role of these key financial ratios in shaping firm profitability while capturing parameter uncertainty and uncovering non-linear patterns that traditional models often overlook. The significance of this investigation lies in its ability to integrate a theory-based probabilistic model with an interpretable machine-learning technique, enabling more precise estimation and clearer identification of which financial indicators carry the greatest relevance for firm performance. The novelty of this work emerges from the introduction of a hybrid analytical framework that jointly evaluates posterior distributions and model-based explanations, an approach rarely applied in accounting and finance research. Through this integration, the study contributes to the literature in three ways. First, it enriches the understanding of profitability determinants in emerging markets by empirically reinforcing the Resource-Based View (RBV), Trade-Off Theory, and Agency Theory using complementary analytical tools. Second, it provides a methodological contribution by demonstrating how probabilistic inference and interpretable ML can be combined to generate insights at both the market and firm-specific levels. Third, it offers practical value for managers, investors, and policymakers by clarifying the financial conditions that most strongly influence profitability, particularly asset utilization efficiency and balanced leverage, thereby supporting strategy development and policy design in environments characterized by uncertainty.

LITERATURE REVIEW

Resource-Based View (RBV)

RBV explains differences in firm performance based on internal resources that are valuable, rare, inimitable, and non-substitutable, and recent empirical studies continue to show that such resources drive profitability, especially under volatile conditions in emerging and dynamic markets. Contemporary RBV-based research highlights that operational efficiency and the strategic deployment of internal resources are central mechanisms through which firms translate resource endowments into superior financial

outcomes, reinforcing the view that performance is rooted in how effectively resources are managed rather than merely possessed. In this context, financial ratios such as TATO and NPM can be interpreted as quantitative indicators of resource utilization efficiency, capturing how well firms convert their asset base and revenue into profits and thereby linking resource management decisions directly to profitability. However, many RBV-oriented empirical studies still rely on mean-based estimation techniques that inadequately reflect firm-specific heterogeneity in resource deployment and efficiency, leading to an oversimplified picture of how internal resources affect performance. To address this limitation, the present study extends RBV applications by employing Bayesian regression to obtain full posterior distributions and credible intervals for the effects of key financial ratios, enabling explicit modelling of parameter uncertainty and firm-level variation in resource utilization efficiency within the LQ45 context (Arbelo-Pérez et al., 2023; da Silva et al., 2025; Piao & Choi, 2022; Putri & Rahmat, 2025).

Trade-Off Theory of Capital Structure

The Trade-Off Theory suggests that companies establish their ideal capital structures by weighing the tax advantages of debt against the potential costs associated with financial distress (Modigliani & Miller, 1963). The DAR is frequently utilized as a standard measure for leverage in the study of capital structure. The empirical evidence presents a varied picture: certain studies suggest that moderate leverage can boost profitability through tax advantages, whereas other research points to the fact that high levels of leverage may elevate bankruptcy risk and diminish firm value (Zeitun & Tian, 2007). This investigation tackles the inconsistency by utilizing Bayesian inference, which accounts for parameter uncertainty, alongside interpretable ML (XGBoost-SHAP), which measures the feature-level contributions of DAR to ROA.

Agency Theory and Liquidity Management

Agency Theory indicates that an abundance of liquidity can intensify agency issues, as managers might misallocate free cash flows, resulting in inefficiencies (Jensen, 1986). The CR serves as a standard metric for assessing liquidity and short-term financial stability. Some evidence indicates that increased liquidity enhances a firm's capacity to fulfill its obligations, whereas other research contends that surplus liquidity can result in inefficient capital allocation (Opler et al., 1999). The Bayesian–XAI approach provides a detailed insight into the impact of liquidity on profitability among diverse firms, addressing the shortcomings of mean-based models.

Empirical Findings on Financial Ratios and Profitability

Previous studies highlight the mixed effects of financial ratios on profitability. Liquidity has shown both positive and negative impacts. Leverage exhibits a non-linear relationship with firm value. Firms with higher profit margins typically demonstrate superior profitability due to effective cost control (Yazdanfar, 2013). Asset utilization efficiency, reflected in TATO, is consistently linked to higher profitability. However, the majority of these studies use conventional regression models, which fail to account for firm-specific heterogeneity and lack probabilistic inference.

Methodological Gap and Study Contribution

Recent advancements support the integration of Bayesian inference with interpretable ML to enhance the quality of inference and transparency (Klimova, 2022). Bayesian methods yield insights into parameter uncertainty and credible intervals, whereas ML models like XGBoost deliver impressive predictive accuracy, albeit with restricted interpretability. SHAP values address this limitation by assigning model predictions to specific features, thereby improving explainability. Despite these advancements, there is a scarcity of studies in accounting and finance that have integrated these tools to

examine firm profitability, especially in emerging markets (Fallatah, 2021; Gao et al., 2024).

By bridging these theoretical and methodological gaps, this study contributes by (1) extending RBV, Trade-Off Theory, and Agency Theory applications in emerging markets through probabilistic inference; (2) introducing a hybrid Bayesian–XAI framework that combines robust inference with interpretable prediction; and (3) offering actionable insights on how liquidity, leverage, profit margins, and asset utilization efficiency jointly affect firm profitability at both aggregate and firm-specific levels.

Hypotheses Development

Current Ratio (CR) and Return on Assets (ROA)

The relationship between CR and ROA continues to receive considerable attention in financial management research, as CR plays a central role in determining a firm's ability to operate smoothly and generate stable profits. CR represents the most liquid component of a firm's resources, and its availability ensures that companies are able to meet short-term obligations, manage operational cycles, and maintain resilience during periods of financial pressure. Because ROA reflects how effectively a firm uses its total assets to produce profit, the management of the CR becomes an important indicator of whether available resources are being used productively.

Recent studies highlight that firms that maintain sufficient levels of CR tend to show better financial performance. Jonathan and Purwaningsih (2023) argue that liquidity derived from the CR supports day-to-day activities and strengthens investor confidence. According to their findings, when companies maintain a balanced CR, they project stability to external stakeholders and are more likely to achieve higher ROA. Their work emphasizes that the management of short-term assets is not merely an operational concern but also a strategic factor that contributes to overall profitability.

Additional support comes from the research of Kramarić et al. (2021), which examines how current asset management relates to several financial indicators, including ROA. Their results show that firms with stronger control over their CR generally achieve more favorable ROA outcomes. By managing receivables, inventories, and cash resources effectively, companies reduce unnecessary costs and improve operational efficiency, leading to better profitability. This suggests that attention to the CR directly shapes the effectiveness with which firms convert resources into earnings.

Rahman et al. (2021) further stress the importance of the CR in protecting firms from financial distress. They note that companies with well-managed CR are better prepared to handle unexpected cash flow disruptions, which helps ensure business continuity. The ability to avoid financial strain contributes to sustained profitability and, over time, supports stronger ROA figures. Their study highlights that current asset management is linked to both operational stability and long-term financial performance.

The relevance of this relationship also appears across different sectors. Zuraida et al. (2024), for example, show that in agriculture-based industries, the management of CR, including livestock feed supplies, crop inventories, and other seasonal inputs, can directly influence profitability. Their findings indicate that the economic role of the CR is substantial and that efficient management practices lead to higher ROA even in industries with variable production cycles. Similarly, the work of Endri et al. (2020) points out that firms with significant current asset holdings tend to perform better financially when these assets are managed carefully. According to their study, firms that consistently monitor and adjust their current asset structure exhibit more stable profitability, again reflected in positive ROA outcomes.

Collectively, these studies present a consistent pattern suggesting that the effective management of the CR strengthens liquidity, enhances operational efficiency, and contributes to higher profitability as measured by ROA. The convergence of findings from various research contexts supports the argument that current asset management is an important financial practice and provides a clear basis for examining its influence on ROA in the present study.

H1: CR has a significant positive effect on ROA.

Debt-to-Asset Ratio (DAR) and Return on Assets (ROA)

The relationship between the DAR and ROA continues to be examined widely because leverage is a central component of financial structure and has direct implications for a firm's ability to generate profit from its asset base. DAR reflects the proportion of a firm's assets that are financed by debt, and changes in this ratio often influence both financial risk and operational efficiency. As ROA represents a firm's ability to convert total assets into earnings, understanding how DAR interacts with financial performance helps explain broader patterns of profitability across sectors.

Studies conducted from 2020 to 2023 reveal that the effect of DAR on ROA varies depending on industry characteristics, financial policies, and external conditions. Research by Saif-Alyousfi (2020), which analyzes banking performance across 47 Asian countries, indicates a positive connection between bank size and profitability indicators, including ROA. While the study focuses on size rather than DAR directly, the findings imply that banks with stronger asset positions may be able to employ leverage more effectively, suggesting that higher DAR can support profitability when managed in line with economies of scale.

Evidence from Turkish banks presented by Kaya et al. (2021) shows that leverage can play a dual role. In some situations, DAR helps stabilize asset utilization and improve ROA; in others, excessive leverage heightens financial distress and constrains profitability. This supports the view that moderate levels of leverage can support operational efficiency, but firms that rely too heavily on debt may experience declining ROA due to increased financial pressure.

Sector-specific studies also highlight the role of DAR in shaping profitability. In the food and beverage industry, Endri et al. (2020) report that maintaining a balanced DAR contributes to profit growth, indirectly enhancing ROA. Their study emphasizes the importance of monitoring financial ratios as indicators of operational health and long-term performance. Helman (2021) adds that while DAR alone may not always show a strong effect on ROA, its interaction with other financial ratios provides a more complete picture of a company's financial condition, particularly in consumer goods companies where leverage decisions are closely tied to market stability.

Aji and Tantri (2024) examine the healthcare sector and show that DAR and ROA interact significantly in shaping stock price outcomes, illustrating that leverage decisions and profitability indicators are complementary tools for evaluating financial viability. Similarly, Anindita and Lestari (2023), studying the retail sector during the COVID-19 pandemic, find that shifts in DAR significantly influenced ROA during periods of fluctuating consumer demand and operational uncertainty. Their results point to the sensitivity of ROA to leverage adjustments, especially when firms face external shocks.

Additional evidence is provided by Mamun et al. (2022), who observe a negative relationship between capital adequacy and ROA in the banking sector. Since capital

adequacy affects leverage decisions, their findings suggest that changes in DAR can materially influence profitability outcomes. Tarihoran and Endri (2021) further show that DAR helps predict earnings changes and future profitability in consumer goods firms, suggesting that carefully increasing debt relative to assets can improve profitability when firms maintain sufficient control over their operations.

Taken together, these studies indicate that the effect of the DAR on ROA is not uniform across all settings. Instead, it depends on how effectively firms balance the benefits of leverage, such as enhanced asset productivity, with the risks posed by financial distress. Firms that manage their leverage in alignment with their operational capacity tend to achieve stronger ROA, while those that use debt excessively or inefficiently may experience diminished financial performance.

In line with these findings, the literature provides a reasonable basis to propose the following hypothesis:

H2: DAR has a significant effect on ROA.

Net Profit Margin (NPM) and Return on Assets (ROA)

The relationship between NPM and ROA has been widely discussed across recent financial studies, as both indicators represent key components of a firm's profitability structure. NPM reflects the portion of revenue that remains as net profit after all expenses are accounted for, while ROA measures the efficiency with which a company uses its assets to generate earnings. Understanding how NPM contributes to variations in ROA is therefore important for evaluating overall financial health and managerial effectiveness. A review of relevant publications from 2020 to 2025 provides a clearer picture of how previous research has approached this connection and the extent to which NPM may shape asset-based returns.

Research in the insurance sector by Bustani (2020) shows that profitability ratios, particularly NPM, influence stock prices, suggesting that firms capable of maintaining healthy profit margins tend to achieve stronger financial outcomes, including improvements in ROA, even though the study does not explicitly isolate the direct effect. Studies in the banking sector also reflect this pattern. Muktiadji and Pamungkas (2022) report that NPM contributes meaningfully to stock valuation among Indonesian banks, indicating that profit margin stability signals better financial management, although they do not provide detailed evidence on how this margin translates specifically into ROA performance. Similar observations were made by Hartanto (2023), who notes that firms with higher NPM often adopt asset management strategies that support better profitability outcomes. Even if the study does not directly quantify the link between NPM and ROA, it provides conceptual support for the idea that stronger margins may improve the way assets generate earnings.

A more explicit connection appears in the empirical findings of Rafikawaty and Hertina (2024), who examine post-acquisition corporate performance. Their results show that shifts in NPM produce measurable changes in ROA, indicating that profitability margins directly influence asset-based returns during periods of organizational adjustment. Further evidence comes from the work of Natsir and Bangun (2025), who demonstrate that NPM contributes significantly to ROA across firms experiencing operational expansion. Their findings suggest that profit margins must be managed carefully because even slight fluctuations can affect the effectiveness with which assets generate earnings. Complementing these sector-specific insights, the review by Demetriades and Owusu-Agyei (2022) states that higher NPM values often reflect improved internal

financial processes, which tend to be accompanied by higher ROA, although the effect may vary depending on industry conditions and cost structures.

Overall, the reviewed literature indicates that NPM plays a meaningful role in shaping ROA, either directly or through broader financial mechanisms that influence the efficiency of asset utilization. While the strength of the relationship differs across industries and organizational contexts, the general pattern suggests that firms capable of converting revenue into net income more effectively tend to achieve better asset-based profitability. These studies collectively support the expectation that NPM contributes positively to ROA, providing a reasonable foundation for proposing a direct influence of profit margin performance on asset returns.

Accordingly, the following hypothesis is formulated:

H3: NPM has a significant positive effect on ROA.

TATO and Return on Assets (ROA)

TATO has been widely examined in recent financial literature because it reflects how effectively firms utilize their assets to generate revenue, making it an important indicator when assessing variations in ROA. Scholars generally agree that TATO represents a firm's operational efficiency, and improvements in this ratio often coincide with stronger asset-based profitability. Reviewing studies published between 2021 and 2024 provides insight into how TATO contributes to ROA and how these findings appear across different industrial contexts.

Gunawan et al. (2022) provide clear empirical evidence that TATO has a positive and significant effect on ROA, showing that companies capable of managing their assets efficiently tend to achieve higher earnings relative to their asset base. Their findings suggest that the daily operational decisions made by managers, such as optimizing production capacity or improving inventory cycles, have direct implications for financial performance. A similar conclusion is presented by Nuryani (2024), who examines the Indonesian property and real estate sector and reports that firms with higher TATO are more successful in achieving superior ROA. This study highlights that industries with large asset structures depend heavily on efficient utilization, making TATO a crucial factor in overall profitability. Taken together, these two studies suggest that companies that streamline asset usage tend to achieve better financial outcomes, particularly in sectors where assets represent substantial long-term investments.

Other perspectives in the literature offer additional insights. Anuar et al. (2021) analyze TATO in relation to broader firm performance measures and find that while TATO shows a meaningful connection with profitability, the effect is more pronounced on ROE than on ROA. This distinction shows that TATO may play different roles depending on the profitability metric being observed. Meanwhile, evidence from the consumer goods sector provided by Tarihoran and Endri (2021) indicates that high asset turnover contributes positively to profitability levels, reaffirming that strategic use of assets is closely tied to improved ROA. Their work complements the earlier findings by demonstrating that even in fast-moving industries with competitive pressures, firms that facilitate productive use of their asset base are more likely to achieve favorable financial outcomes.

However, not all studies report consistent results. Widjayanti and Aslamiyah (2024) find a negative and statistically insignificant relationship between TATO and ROA in their analysis, suggesting that certain conditions, such as firm size, market instability, or inconsistent asset management practices, may reduce the influence of TATO on asset

returns. This divergence indicates that while the general trend in the literature points toward a positive connection, variations across sectors and methodological approaches may contribute to occasional differences in empirical outcomes. Such findings also imply that firms should consider the broader context in which asset utilization takes place, as external conditions can alter the effectiveness of operational strategies.

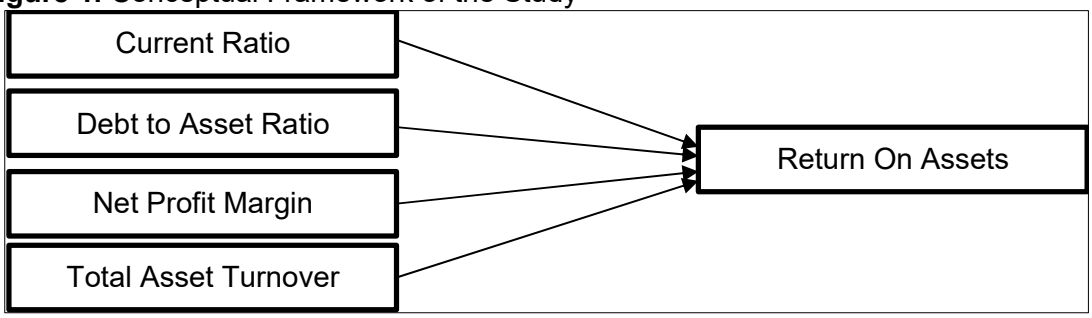
Overall, the reviewed literature indicates that TATO plays an important role in shaping a firm's financial performance, particularly through its influence on ROA. Most studies demonstrate that firms achieving higher asset turnover tend to experience stronger asset-based profitability because they are able to convert operational activities into earnings more effectively. Although a few exceptions appear in certain industry settings, the broader pattern shows that efficient asset management remains central to improving ROA. This consistent line of evidence provides a clear rationale for proposing that TATO contributes positively to a firm's ability to generate returns from its assets.

Based on the empirical and theoretical support presented in the literature, the following hypothesis is formulated:

H4: TATO has a significant positive effect on ROA.

Figure 1 presents the conceptual framework used in this study.

Figure 1. Conceptual Framework of the Study



RESEARCH METHOD

This study utilizes a quantitative explanatory research design to explore the impact of essential financial ratios (CR, DAR, NPM, and TATO) on the profitability of firms. An integrated analytical framework utilizes Bayesian regression for probabilistic inference alongside XGBoost and SHAP to achieve both high predictive performance and interpretability.

Data and Sample

The analysis employs secondary panel data derived from the audited annual reports of 20 firms that have been consistently listed in the LQ45 index of the IDX for a minimum of two consecutive years between 2020 and 2023, resulting in 80 firm-year observations.

The sample was selected using a purposive sampling strategy based on several criteria to ensure data consistency across years and maintain the integrity of the panel structure. The selection process proceeded as follows.

The initial population consisted of 65 firms that appeared in the LQ45 Index at any time during the 2020–2023 period. To avoid entry–exit bias and ensure panel stability, only firms that remained continuously listed in the LQ45 Index for the entire four-year period were retained; this criterion excluded 40 firms. Next, firms that did not provide complete

financial statements for all fiscal years from 2020 to 2023 were removed; however, no firms were excluded under this rule. Firms that recorded consecutive losses during the observation period were also excluded to avoid bias in the profitability-based outcomes, although none met this condition. Finally, firms whose financial statements were not reported in Indonesian rupiah were removed to ensure comparability of financial metrics, resulting in the exclusion of five firms.

After applying all criteria, the final sample comprised 20 firms, yielding 80 firm-year observations for the 2020–2023 analysis period. These criteria were implemented to ensure comparability, panel consistency, and reliable estimation in both the Bayesian and XGBoost modeling frameworks. No missing data were detected after data validation. The dependent variable is ROA, which is calculated by dividing net income by total assets. Independent variables are articulated as follows: CR = Current Assets / Current Liabilities; DAR = Total Debt / Total Assets; NPM = Net Income / Net Sales; and TATO = Net Sales / Total Assets. All predictors were standardized to improve numerical stability in Bayesian estimation and to make the regression coefficients directly comparable across predictors measured in different units.

Bayesian Regression

The implementation of Bayesian regression utilized the `stan_glm` function from R's rstanarm package, which offers comprehensive posterior distributions and credible intervals for the parameters of the model. All predictors underwent standardization before estimation. The specification of the model is as follows:

$$ROA\_i = \beta_0 + \beta_1 CR_i + \beta_2 DAR_i + \beta_3 NPM_i + \beta_4 TATO_i + \epsilon_i$$
$$\text{where } (\epsilon_i \sim N(0, \sigma^2)).$$

Four chains of 2,000 iterations each were utilized for Markov Chain Monte Carlo (MCMC) sampling, resulting in 4,000 posterior samples following the warm-up phase. Convergence diagnostics, including R-hat statistics and effective sample sizes, indicated satisfactory convergence, with all R-hat values approximately equal to 1. Weakly informative normal priors N (0,5) were utilized for the regression coefficients. The evaluation of model adequacy involved the use of posterior predictive checks, Bayesian R^2, and leave-one-out cross-validation (LOO) as outlined by Vehtari et al. (2024) and Yao et al. (2018).

XGBoost

XGBoost was utilized to attain superior predictive accuracy. Hyperparameters such as learning rate, maximum tree depth, and the number of boosting rounds were optimized through five-fold cross-validation to mitigate the risk of overfitting. The evaluation of model accuracy was conducted through the use of Root Mean Square Error (RMSE) and Mean Absolute Error (MAE), aligning with established methodologies in previous predictive modelling studies (Willmott & Matsuura, 2005).

Model Interpretability with SHAP

SHAP values were calculated to measure the contribution of each predictor to individual predictions, thereby improving interpretability. Global interpretability was assessed through SHAP summary plots and Partial Dependence Plots (PDP), while local explanations were offered for predictions specific to individual firms. This method addresses the concerns surrounding the opacity of ML models in the fields of accounting and finance (Willmott & Matsuura, 2005).

Contribution of the Hybrid Framework

Combining Bayesian regression and XGBoost-SHAP enables both robust inference and high predictive accuracy. Bayesian methods provide parameter uncertainty estimates, allowing probabilistic statements about effects, particularly valuable in small-sample contexts. XGBoost ensures predictive strength, and SHAP enhances transparency, enabling richer insights into feature importance. The integration addresses the growing demand for explainable AI in accounting and finance research (Gao et al., 2024).

RESULTS

Descriptive Statistics

Table 1. Descriptive Statistics

	Variable	Mean	SD	Min	Max
1	ROA	0.0812	0.0788	0.0037	0.3489
2	CR	1.2609	1.0969	0.0148	4.9081
3	DAR	0.6538	0.8329	0.1455	7.7294
4	NPM	0.3006	0.2889	0.0143	0.8598
5	TATO	0.6359	0.5971	0.0059	2.3170

Source: Developed by the Authors

The descriptive statistics for all variables analyzed in this study are presented in Table 1. The mean ROA for the 80 firm-year observations is 0.0812, accompanied by a standard deviation of 0.0788. TATO and NPM show greater variability than CR and DAR, suggesting variations in operational efficiency and profitability margins among the firms analyzed.

Bayesian Regression

Table 2. Bayesian Regression Results

	Predictor	Mean	SD	2.5%	97.5%	Significance
1	CR	0.00	0.00	-0.011	0.012	Not significant
2	DAR	0.01	0.00	0.004	0.025	Significant
3	NPM	0.01	0.00	-0.002	0.026	Weak evidence
4	TATO	0.07	0.00	0.059	0.084	Significant

Source: Developed by the Authors

Table 2 summarizes the Bayesian regression estimates for all predictors. The TATO exhibits the strongest positive association with ROA, with a posterior mean of 0.07 and a 95% credible interval ranging from 0.059 to 0.084, providing clear evidence of a meaningful effect. The DAR also shows a positive and statistically credible influence on ROA (posterior mean = 0.01; 95% CrI = 0.004 to 0.025). The NPM presents only weak evidence of a positive association, as its posterior mean of 0.01 is accompanied by a 95% credible interval of –0.002 to 0.026, which marginally overlaps zero. In contrast, the CR demonstrates no discernible effect on ROA, with a posterior mean essentially equal to zero and a credible interval of –0.011 to 0.012, indicating a lack of statistical significance.

Posterior predictive checks validated that the predicted ROA aligned closely with the observed values. The leave-one-out cross-validation yielded an elpd_loo of 132.6 and a looic of −265.2, suggesting that the model demonstrates a strong fit. The Bayesian R^2 value was 0.70, accompanied by a 95% credible interval ranging from 0.60 to 0.78. This indicates that around 70% of the variance in ROA is accounted for by the model.

Figure 2. Posterior Coefficient Distributions

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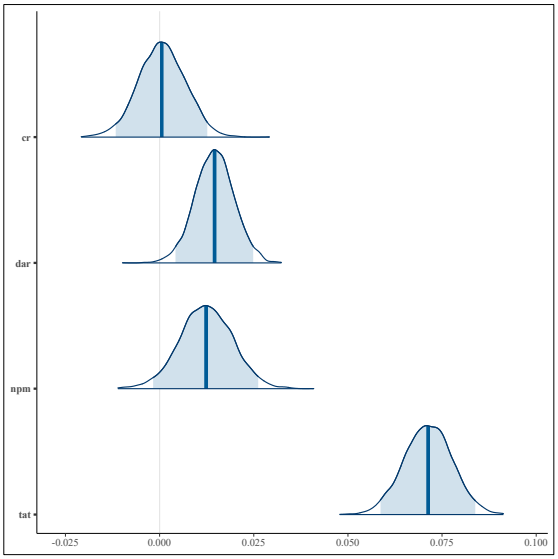
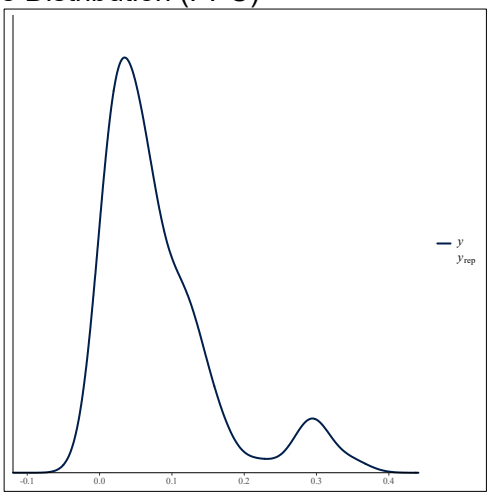


Source: Developed by the Authors

The posterior distributions of the regression coefficients derived from the Bayesian model are illustrated in Figure 2. TATO exhibits a distinctly positive distribution, DAR indicates a modest positive effect, whereas NPM's credible interval shows a slight overlap with zero. The distribution of CR is primarily focused around zero, suggesting a minimal effect on ROA.

Figure 3. Posterior Predictive Distribution (PPC)



Source: Developed by the Authors

Figure 3 displays the posterior predictive distribution of ROA obtained from the Bayesian regression model. The predicted distribution closely matches the observed data, indicating that the model provides a good fit.

XGBoost Model

Table 3. XGBoost Feature Importance

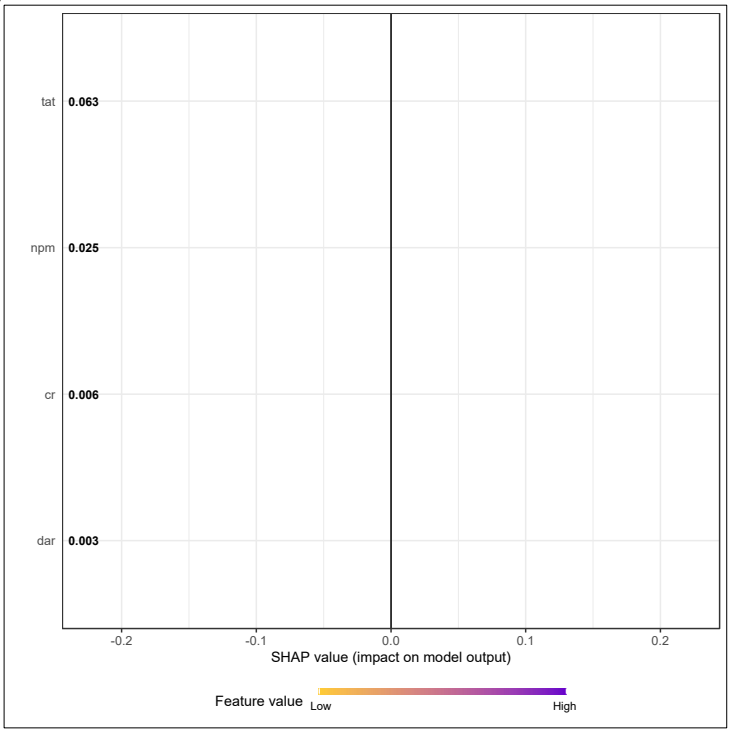
	Feature	Gain	Cover	Frequency
1	TATO	0.763	0.420	0.331
2	NPM	0.171	0.267	0.302
3	DAR	0.052	0.077	0.081
4	CR	0.014	0.236	0.285

Source: Developed by the Authors

The XGBoost model demonstrated impressive predictive capabilities, yielding an RMSE of 0.018 and an MAE of 0.013. The results of feature importance from the XGBoost model are displayed in Table 3, indicating that TATO had the greatest contribution to the model's predictive capability, followed by NPM, DAR, and CR. To maintain comparability across the two analytical approaches (Bayesian regression and XGBoost), the XGBoost model in this study was implemented as a baseline specification using the default hyperparameter settings of the XGBoost library. This includes squared–error loss (objective = "reg:squarederror"), a learning rate of 0.3, maximum tree depth of 6, subsampling and column sampling rates of 1.0, and 10 boosting rounds. The model was evaluated using an 80/20 train–test split rather than k-fold cross-validation because the purpose of the XGBoost component was not full hyperparameter optimization, but rather the provision of a machine-learning benchmark for comparison with the Bayesian models. This is acknowledged as a methodological limitation, and future research may incorporate systematic cross-validated tuning to improve generalizability.

SHAP Values

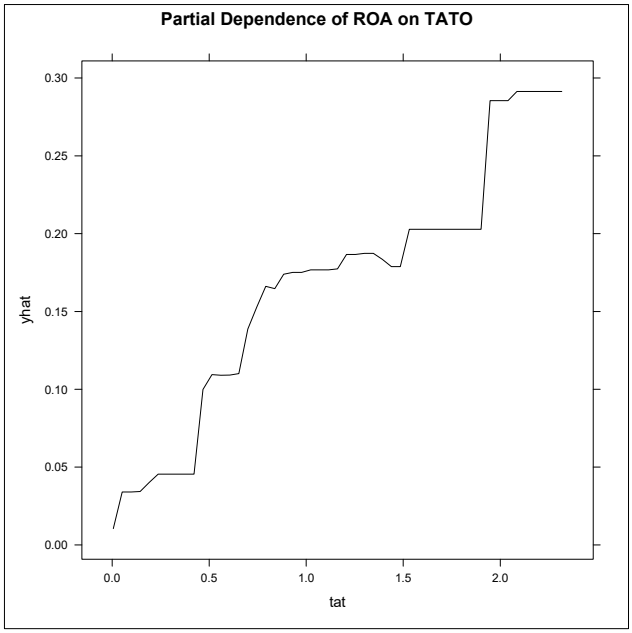
Figure 4. Summary of SHAP Values for Model Predictors



Source: Developed by the Authors

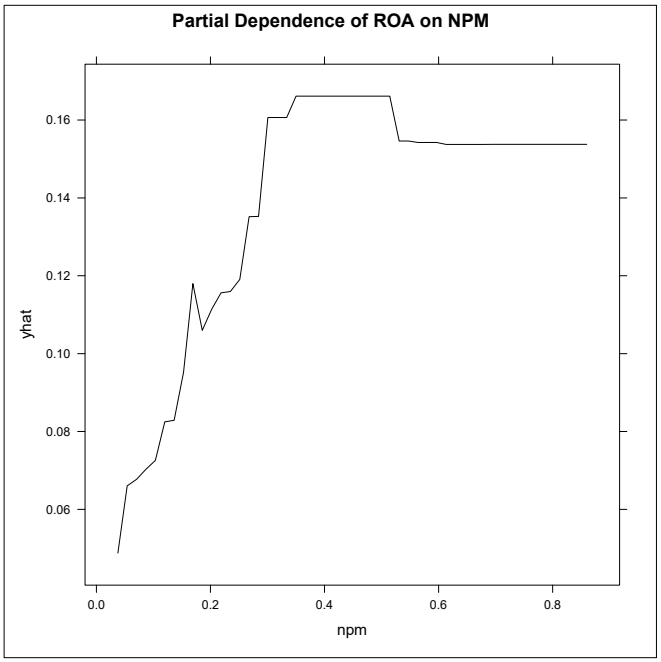
Figure 4 shows the SHAP summary plot, which illustrates the relative importance and direction of each predictor's effect on ROA. TATO is the dominant predictor, where higher values are associated with increased ROA. NPM also has a positive contribution, though it is less substantial than TATO. DAR has a minor positive impact, while CR exerts minimal influence. These findings are consistent with the Bayesian estimates and reinforce that asset utilization is the primary driver of profitability.

Figure 5. Partial Dependence Plot for TATO



Source: Developed by the Authors

Figure 6. Partial Dependence Plot for NPM



Source: Developed by the Authors

Figure 7. Partial Dependence Plot for CR

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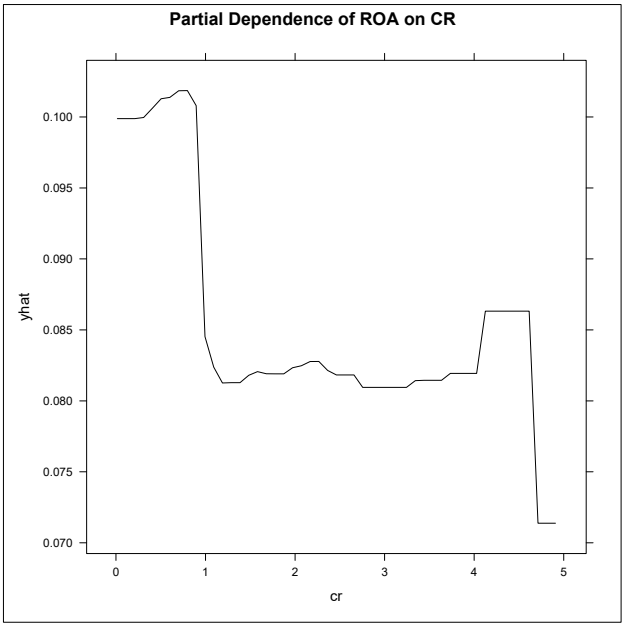
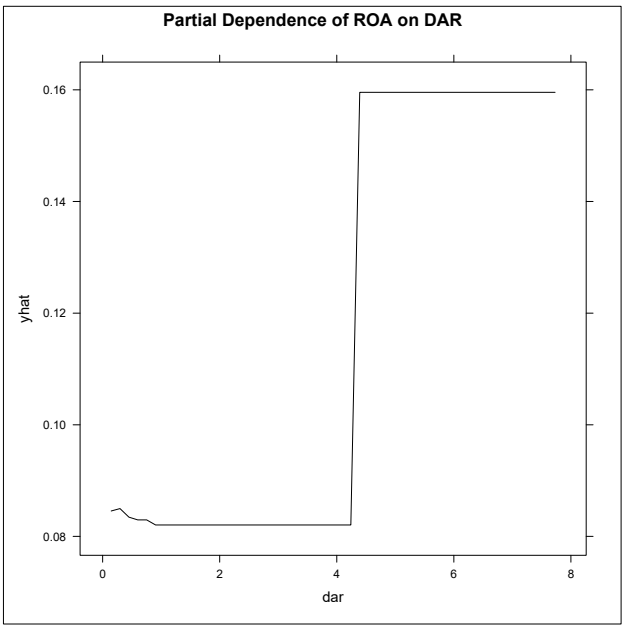


Source: Developed by the Authors

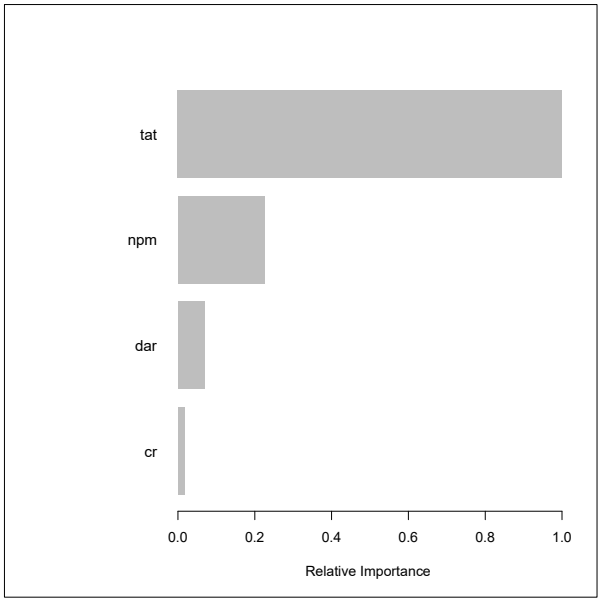
Figure 8. PDP for DAR



Source: Developed by the Authors

Figures 5 to 8 display the PDP for TATO, NPM, CR, and DAR. Figure 5 shows that ROA increases as TATO rises, although the effect levels off at higher values, indicating diminishing returns to asset utilization efficiency. Figure 6 demonstrates a positive but moderate effect of NPM on ROA, with reduced incremental gains at higher levels. Figures 7 and 8 indicate that CR has little influence on ROA, while DAR contributes positively in a non-linear pattern, where moderate leverage results in better profitability.

Figure 9. XGBoost Feature Importance



Source: Developed by the Authors

The results of feature importance obtained from the XGBoost model are illustrated in Figure 9. The horizontal bars illustrate the relative contribution of each predictor to the model's predictive power, as determined by the Gain metric. The largest contribution comes from TATO, followed by NPM, DAR, and CR.

This result confirms that TATO is the dominant factor driving the model's predictions, consistent with the Bayesian regression results and SHAP analysis. The alignment across methods enhances confidence in the robustness of the findings.

Hypotheses Findings

The results show that H1 is rejected, as CR exhibits no significant effect on ROA, evidenced by the near-zero posterior mean and a credible interval crossing zero in Table 2, with Figure 2 also showing a coefficient distribution centered around zero. H2 is accepted, supported by the positive and statistically credible effect of DAR on ROA in Table 2, further reinforced by the positive distribution in Figure 2 and its moderate importance in Table 3. H3 is rejected, since NPM presents only weak evidence of influence on ROA; its credible interval overlaps zero in Table 2, and Figure 2 confirms this marginal effect, despite moderate importance in the XGBoost model. H4 is accepted, as TATO demonstrates the strongest and clearly positive effect on ROA in Table 2, with Figure 2 showing a fully positive posterior distribution and Table 3 confirming it as the most influential predictor.

The overall results highlight that TATO is the most influential determinant of profitability for LQ45 firms. NPM and DAR play supporting roles, while CR is not a meaningful predictor. Combining Bayesian regression with XGBoost-SHAP and PDP analyses provides both robust statistical inference and transparent predictive insights, improving the interpretability and reliability of the findings for academic and practical applications.

DISCUSSION

The findings indicate that TATO significantly impacts ROA, aligning with the RBV, which emphasizes the critical role of efficient resource utilization in achieving competitive advantage (Gunawan et al., 2022). An increase of 10% in TATO results in an estimated 0.7% enhancement in ROA (95% credible interval: 0.59%–0.84%), suggesting that firms can achieve greater profitability by focusing on operational efficiency improvements

rather than making adjustments to their capital structure. This suggests that companies in developing markets like Indonesia attain greater profitability not just by owning resources but by effectively utilizing those resources to yield returns. Recent studies highlight that the efficiency of asset utilization is vital for maintaining firm performance in ever-changing market conditions (Alawneh, 2022). In agreement with Klimova (2022), the results indicate that advancements in operational efficiency and strategies related to ESG can collectively strengthen a firm's resilience and contribute to its long-term financial performance.

The notable yet comparatively modest impact of the DAR lends credence to the Trade-Off Theory of Capital Structure, which posits that companies establish their ideal leverage by weighing the advantages of debt, including tax shields, against the drawbacks of financial distress (Modigliani & Miller, 1963). The findings indicate that a balanced level of leverage can improve profitability, while an overabundance of debt may negatively impact firm performance. This aligns with findings from other developing economies, indicating that companies with balanced capital structures often realize improved long-term financial results (Dsouza et al., 2025).

The weak evidence for the effect of NPM indicates that profitability margins alone are not sufficient to enhance ROA without efficient asset utilization. This finding extends the RBV by showing that it is not merely high profit margins that matter, but the ability to translate those margins into returns through effective use of assets (Vehtari et al., 2024). Meanwhile, the CR shows no meaningful influence on profitability, which is in line with Agency Theory arguments that excess liquidity can lead to inefficient resource allocation due to managerial discretion (Jensen, 1986).

Methodologically, this study contributes by integrating Bayesian regression with XGBoost-SHAP analysis. Bayesian regression offers a probabilistic framework that produces full posterior distributions of parameters, allowing for a richer understanding of uncertainty compared to conventional mean-based methods. XGBoost, a high-performance ML algorithm, was combined with SHAP values to provide interpretable predictions, thus addressing a key criticism of ML models as being black-box approaches (Carvalho et al., 2019). This hybrid approach aligns with the growing trend of combining statistical inference with predictive modelling to improve both explanation and forecasting in accounting and finance research. By leveraging explainable AI, the study addresses the persistent criticism that ML lacks transparency and bridges the gap between theory-driven and data-driven methods (Liaras et al., 2024).

The findings hold significant relevance for managers, investors, and policymakers. The findings emphasize the importance for managers to focus on operational strategies that enhance asset utilization efficiency, rather than solely concentrating on boosting profit margins or liquidity levels. Firms exhibiting higher asset turnover and moderate leverage may be perceived as more appealing investment opportunities, given the evident correlation between these factors and profitability. Regulatory frameworks should be crafted by policymakers to motivate firms to boost operational efficiency and embrace sustainable capital structures, which would contribute to enhanced financial stability in emerging markets. This finding is consistent with recent evidence indicating that practices focused on ESG can boost long-term profitability by enhancing operational efficiency.

While this study offers valuable insights, it is important to acknowledge its limitations. The analysis is based exclusively on secondary financial data, which may not adequately reflect other firm-specific attributes like governance practices, strategic decision-making, or ESG initiatives. Future studies could build upon these findings by integrating

governance and ESG elements, utilizing Bayesian hierarchical models to address firm- and industry-level differences, or merging financial data with textual ESG disclosures to offer deeper insights into the factors influencing firm performance in emerging markets.

CONCLUSION

This investigation analyzed the impact of essential financial ratios (CR, DAR, NPM, and TATO) on firm profitability, as indicated by ROA, for LQ45 companies listed on the IDX from 2020 to 2023. The integration of Bayesian regression with XGBoost-SHAP analysis yielded both probabilistic inference and interpretable predictive modeling, effectively addressing methodological gaps in accounting and finance research, especially within emerging markets.

The results indicate that TATO stands out as the primary factor influencing profitability, with DAR following closely behind. In contrast, NPM exhibits a lesser impact, and CR appears to have no significant effect. The findings support the RBV, which posits that the effective use of valuable and rare resources results in enhanced performance. The findings offer empirical backing for the Trade-Off Theory of Capital Structure, indicating that moderate leverage enhances profitability by striking a balance between tax advantages and the costs associated with financial distress (Modigliani & Miller, 1963). On the other hand, the negligible impact of CR is consistent with Agency Theory, which suggests that surplus liquidity can result in ineffective managerial choices and less-than-ideal resource distribution (Jensen, 1986).

This study offers a significant theoretical contribution to the existing literature by illustrating that the integration of Bayesian inference with explainable ML yields deeper insights compared to traditional mean-based methods. This approach connects theoretical frameworks with empirical data techniques, addressing the demand for enhanced methodological creativity in the fields of accounting and finance research. The integration of probabilistic inference with interpretable ML enhances the understanding of the impact of financial ratios on profitability at both aggregate and firm-specific levels.

The results have several practical implications. For corporate managers, the findings suggest that strategies aimed at improving operational efficiency and asset utilization are more effective in enhancing profitability than merely increasing profit margins or liquidity. For investors, firms with higher asset turnover and moderate leverage may present more attractive investment opportunities. Policymakers should consider developing frameworks that encourage firms to enhance operational efficiency while maintaining balanced capital structures to ensure long-term financial stability in emerging markets (Klimova, 2022; Wamba et al., 2015).

Future investigations could build upon this study by integrating further firm-level elements like governance frameworks, ESG disclosures, and characteristics specific to various industries. Employing Bayesian hierarchical models may enhance the ability to capture variation across both firm and industry levels. Furthermore, integrating financial data with textual ESG information could yield a more thorough insight into the factors influencing firm profitability in emerging markets.

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DECLARATION OF CONFLICTING INTERESTS

There are no conflicting interests, according to the authors.

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ABOUT THE AUTHOR(S)

1st Author
Junita Silele is affiliated with the Accounting Department, Faculty of Economics and Business, Cenderawasih University, Jayapura, Papua Province, Indonesia. She holds an undergraduate degree in Accounting and is currently continuing her academic development within the field of financial reporting and quantitative analysis. Her research interests focus on corporate performance measurement, accounting information systems, and empirical research using statistical and machine-learning approaches.
Email: junitasilele787@gmail.com
ORCID ID: https://orcid.org/0009-0004-9076-3745

2nd Author
Dr. Maylen Kathrin Petra Kambuaya, SE, M.Si, is a faculty member of the Accounting Department, Faculty of Economics and Business, Cenderawasih University, Jayapura, Papua Province, Indonesia. She earned her bachelor's and master's degrees in Accounting and completed her doctoral studies in the field of economics and finance. She currently serves as a senior lecturer and researcher specializing in public sector accounting, governance, and regional financial management. Her research has contributed to both national and international academic discourse.
Email: maylenkambuaya@feb.uncen.ac.id
ORCID ID: https://orcid.org/0000-0002-3094-4702

3rd Author
Hesty Theresia Salle, SE, M.Ak, is a lecturer at the Accounting Department, Faculty of Economics and Business, Cenderawasih University, Jayapura. She completed her bachelor's and master's degrees in Accounting, with academic interests centered on auditing, financial accounting, and accounting education. She actively participates in various teaching, research, and community service programs within the university.
Email: hesty_salle@akt.feb.uncen.ac.id
ORCID ID: https://orcid.org/0000-0002-8774-3178

4th Author
Ulfah Muslimin, S.ST, M.Ak, is a lecturer at the Accounting Department, Faculty of Economics and Business, Cenderawasih University, Jayapura. She earned her bachelor's and master's degrees in Accounting and is actively engaged in teaching, research, and professional development activities within financial accounting and taxation. Her academic work includes studies on corporate reporting, financial literacy, and regulatory compliance.
Email: ulfah_r@akt.feb.uncen.ac.id
ORCID ID: https://orcid.org/0000-0001-6357-6021

5th Author
Annisa Fitriah Mudassir, SE, M.Ak, is a faculty member of the Accounting Department, Faculty of Economics and Business, Cenderawasih University, Jayapura. She

completed her undergraduate and postgraduate studies in Accounting, focusing on financial accounting, sustainability reporting, and behavioral accounting. She is actively involved in academic teaching, research, and mentoring students in quantitative and qualitative research methods.
Email: annisa_fm@akt.feb.uncen.ac.id
ORCID ID: https://orcid.org/0009-0003-3078-4088

6th Author
Bill Pangayow, SE, M.Si, Ph.D, is a senior lecturer and the Head of the Master of Accounting Program at the Accounting Department, Faculty of Economics and Business, Cenderawasih University, Jayapura, Papua Province, Indonesia. He completed his bachelor's degree in Accounting at Universitas Sam Ratulangi, his master's degree in Accounting at Universitas Diponegoro, and his doctoral degree (Ph.D.) at Philippine Christian University. His academic interests include financial modeling, sustainability accounting, machine learning applications in accounting, and ESG-based reporting. He is an active researcher with numerous national and international publications and serves in various academic leadership roles.
Email: billpangayow@feb.uncen.ac.id
ORCID ID: https://orcid.org/0000-0002-3056-243X