



# Operating expenses enhance employee productivity and strengthen anti-fragility in the pawnshop business causal evidence from double machine learning

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## ABSTRACT

**Background:** Digital transformation has reshaped how firms convert operating expenses into productivity gains, especially in service-based and financial institutions. While prior studies emphasize cost efficiency and technological adoption as performance drivers, evidence on whether rising operating expenses generate positive productivity shocks remains inconclusive. The literature also has not fully examined whether firms can become anti-fragile, where increasing operational costs strengthen capability. This study estimates the causal impact of operating expense growth on employee productivity and examines whether a state-owned financial institution evolves toward an anti-fragile model post-pandemic. **Methods:** This study applies a quantitative causal inference approach using post-pandemic annual secondary data from Pegadaian's audited financial and sustainability reports. Employee productivity is measured by revenue and net profit per employee, with operating expense growth as the main treatment and financial stability indicators as controls. Double Machine Learning isolates the pure causal effect while addressing non-linearity and endogeneity, supported by visual analysis to validate patterns and identify digital efficiency thresholds. **Findings:** The results show a positive and statistically meaningful causal effect of operating expense growth on revenue per employee, with a coefficient of 6,755.68, indicating that higher operational spending significantly enhances productivity. Visual evidence supports anti-fragility, as post-pandemic observations consistently exceed predicted productivity trends, with the peak deviation in 2024, suggesting a digital efficiency threshold where intangible investments yield disproportionate gains, reinforcing anti-fragility theory and extending the Solow residual toward digital capability accumulation. **Conclusion:** The study concludes that strategically managed operating expenses function as productivity-enhancing investments rather than cost inefficiencies, confirming the emergence of an anti-fragile business model. **Novelty/Originality of this article:** This article introduces a causal machine learning framework to operationalize anti-fragility in firm-level productivity analysis and identifies a digital efficiency threshold that has not been empirically documented in prior financial services research.

**KEYWORDS:** anti-fragility; digital transformation; double machine learning; employee productivity; operating expenses.

## 1. Introduction

The pawn-based financial services industry in Indonesia, particularly Pegadaian, is currently undergoing a fundamental structural transformation driven by the accelerated

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digitalization of services, shifts in consumer behavior, and increasing pressure from financial technology disruption (Sugiat & Sudiana, 2020; Putri & Supriadi, 2022). Over the past decade, Pegadaian has no longer operated as a purely labor-intensive entity; instead, it has gradually transitioned toward a capital-technology-intensive business model, as evidenced by rising investments in digital infrastructure, information systems, and application-based service platforms (Nucci et al., 2023; Hendrikse et al., 2018; Sandoyan et al., 2025). This transformation is explicitly reflected in the escalation of operating expenses, particularly those associated with information technology spending, digital application development, and the modernization of internal business processes (Sotnyk et al., 2020; Vaska et al., 2021; Ancillai et al., 2023).

Beyond internal digital transformation pressures, the post-pandemic business environment has also been shaped by broader geo-economic shifts, including financial technology disruption, changing regional capital flows, and increasing competition within digitally integrated financial ecosystems. These transformations have forced state-owned financial institutions to redesign operational structures and strengthen institutional adaptability in response to global economic uncertainty and technology-driven market reconfiguration. In this context, Pawnshop's operational transformation may also be interpreted as a strategic institutional adaptation to emerging geo-economic dynamics in Southeast Asia's evolving financial landscape.

Nevertheless, within conventional economic and management paradigms, increases in operating expenses are almost invariably perceived as indicators of operational inefficiency that may undermine profitability and reduce productivity (Ketokivi & Mahoney, 2020; Yiu et al., 2020; Zhang & Huang, 2023). This perspective is deeply rooted in the logic of static efficiency, wherein organizations are assumed to achieve optimal performance through cost minimization (Radmand et al., 2025; Chiscop et al., 2025; Qabajeh et al., 2023). The primary limitation of this view lies in its inability to adequately explain the dynamics of modern organizations operating in environments characterized by uncertainty, technological disruption, and long-term adaptive pressures (Lee, 2023; Wang et al., 2025; Klumpp & Loske, 2021).

Within this context, this study positions the pawn-based financial services industry particularly Pegadaian as a unique empirical laboratory for testing an alternative hypothesis: that increases in operating expenses do not necessarily signify inefficiency but may instead function as productive stressors that stimulate surges in employee productivity through mechanisms of digital innovation and organizational learning. By adopting the Anti-Fragility framework (Priyadarshini et al., 2022; Jaffe et al., 2023; Nikookar et al., 2024) and integrating it with the concept of the Solow Residual (Briec & Lasselle, 2021; Garbellini & Wirkierman, 2023; Edeki et al., 2024; Freire et al., 2025), this study seeks to reconstruct the traditional perspective on the relationship among costs, technology, and productivity within asset-backed financial service industries.

The central problem underpinning this research lies in the ambiguity of the causal relationship between the growth of operating expenses and employee productivity in the pawn industry amid digital transformation. Empirically, the financial data presented in Figure 1 indicate that Pegadaian experienced a substantial increase in its operating expense ratio over the 2014–2024 period, particularly during the phase of accelerated digitalization and the COVID-19 pandemic crisis. However, this increase raises a fundamental question as to whether higher operating expenses genuinely generate sustained improvements in employee productivity or merely reflect cost inflation driven by bureaucratic inefficiencies and organizational rigidities. Furthermore, conventional analyses based on linear regression often fail to distinguish between spurious correlations and genuine causal relationships, particularly in the context of time-series data influenced by multiple confounding factors such as macroeconomic fluctuations, regulatory changes, and firm-level asset dynamics (Cordoni & Sancetta, 2023; Moraffah et al., 2021; Assaad et al., 2022). As a consequence, strategic decision-making regarding cost allocation is frequently grounded in managerial intuition or normative assumptions rather than robust causal evidence (Feng & Wu, 2022; Zhang et al., 2024).

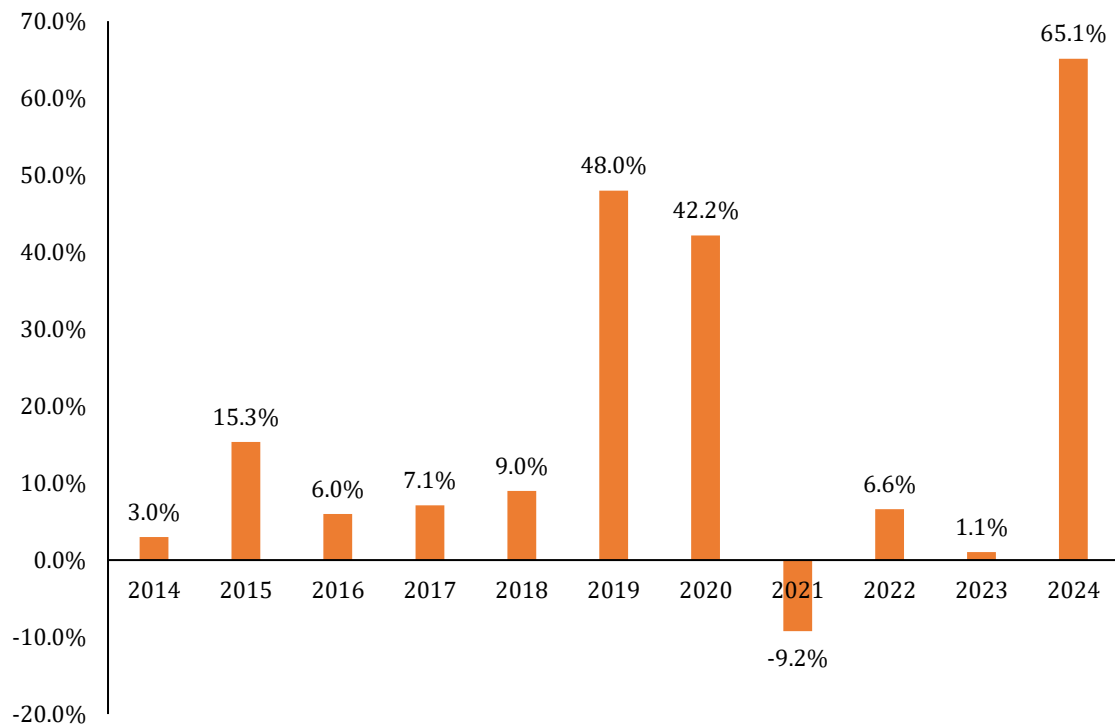


Fig. 1. Graph of significant increase in operating expense ratio  
(Pawnshop financial report, 2025)

The empirical and conceptual literature on digital transformation, artificial intelligence, and Industry 4.0 demonstrates a growing consensus that digitalization positively contributes to labor productivity and workforce performance. Nevertheless, a synthesis of prior studies reveals the persistence of important conceptual, methodological, and contextual gaps that warrant further investigation. The study by Qiu et al. (2025) confirms that digital empowerment enhances productivity and labor quality through economies of scale and managerial efficiency; however, its focus remains confined to public manufacturing firms in China and does not integrate dimensions of cost efficiency and long-term financial stability. Similarly, research by Gao & Feng (2023), as well as Nucci et al. (2023), provides evidence of the significant contribution of digital technologies to total factor productivity, yet their analyses remain predominantly at the aggregate level, thereby overlooking employee-level micro-dynamics and their relationship with firms' operating expense structures. Likewise, Bettiol et al. (2023) document nonlinear effects of Industry 4.0 adoption on SME productivity but do not examine the interaction among productivity, cost structures, and financial risk over longer time horizons.

Other strands of the literature, such as Chen (2022), Seetharaman (2020), and Sewpersadh (2023), primarily emphasize the external drivers of digitalization and business model transformation; however, these contributions remain largely conceptual and provide limited quantitative empirical evidence on labor efficiency and financial performance. Within the financial sector, Campanella et al. (2023) highlight the shift toward capital-intensive business models supported by high-quality human capital, yet their analysis remains oriented toward aggregate efficiency and does not disentangle longitudinal, employee-level productivity dynamics. The findings of Shen & Zhang, (2024) as well as Damioli et al., (2021) suggest that artificial intelligence does not necessarily displace labor; nevertheless, these studies continue to operate at the macro level. Meanwhile, Antonelli et al. (2023), Sima et al. (2020), Surya et al. (2021), Gaglio et al. (2022), and Zhou et al. (2025) underscore the importance of digitalization and innovation but do not explicitly link these processes to the dynamics of operating costs, financial stability, and labor productivity as sustainability indicators.

Based on the cumulative body of literature, three principal research gaps motivate this study. First, productivity research particularly in the financial sector remains dominated by traditional cost-efficiency approaches that conceptualize costs merely as burdens rather than as strategic investments in technological capabilities and human capital. Second, the concept of Anti-Fragility is still largely confined to philosophical and conceptual discussions, with a notable scarcity of empirical evidence grounded in measurable historical data, especially regarding its integration with classical productivity theories such as the Solow Residual. Third, although machine learning methods are increasingly applied in economics, the majority of studies emphasize prediction rather than causal inference. Empirical research employing Double Machine Learning or Causal Forest techniques to estimate the causal impact of operating expenses on employee productivity within the financial industry—particularly the pawn-based financial services sector—remains exceedingly rare.

To address these issues and bridge the identified gaps in the literature, this study proposes a Causal Machine Learning approach—specifically Double Machine Learning (DML)—as its primary methodological solution. This approach enables a clear separation between the treatment variable (growth in operating expenses) and confounding variables (financial ratios, macroeconomic conditions, and asset-liability dynamics), thereby allowing for a more accurate and unbiased estimation of the Pure Treatment Effect. Furthermore, this study formulates a novel conceptual framework that links increases in operating expenses to the formation of a digital productivity residual, defined as a component of productivity that cannot be explained solely by physical capital accumulation but instead arises from digital innovation, process automation, and enhanced employee capabilities. The motivation of this study is both theoretical and practical. From a theoretical perspective, it is driven by the need to challenge the static cost-efficiency paradigm and replace it with a dynamic perspective that recognizes costs as catalysts for adaptation and growth. From a practical standpoint, the study is motivated by Pegadaian's managerial need to assess whether aggressive digital investment strategies genuinely create productivity-enhancing value or instead generate long-term financial burdens.

The primary objective of this study is to reconstruct the traditional understanding of the relationship between cost efficiency and productivity in the pawn-based financial services industry, with a specific focus on Pegadaian Indonesia over the 2014–2024 period. This research seeks to empirically demonstrate whether increases in operating expenses traditionally perceived as operational burdens function instead as strategic investments that shape the Anti-Fragile character of Pegadaian's business model and serve as a principal causal driver of employee productivity, as reflected in higher revenue per employee and net profit per employee. To achieve this objective, the study aims to estimate the pure causal effect of operating expense growth on labor productivity using the Double Machine Learning framework to minimize bias and spurious correlations. In addition, the research seeks to validate the relevance of Nassim Taleb's Anti-Fragility concept in the operational context of financial firms and to integrate it with the Solow Residual perspective in order to identify the hidden contributions of digital innovation embedded within cost components. The study also aims to detect a digital efficiency threshold that is, the phase at which operating expenses cease to represent sunk costs and instead transform into productive investments that generate nonlinear performance improvements. Ultimately, this research is expected to formulate evidence-based cost allocation strategies, enabling future increases in operating expenses to be directed with precision toward strengthening employee capabilities and ensuring the long-term sustainability of firm performance.

Based on the theoretical and empirical gaps identified above, this study is guided by the following central research question: Do strategically increased operating expenses causally enhance employee productivity and contribute to the emergence of anti-fragile organizational capabilities in post-pandemic financial service institutions? In addition, this study asks whether the productivity gains generated through digital operational investment may reflect an extended form of the Solow residual associated with digital capability accumulation and organizational adaptation.

From a theoretical standpoint, this study introduces the Digital Pawnshop Efficiency Curve, a novel conceptual framework that explains the nonlinear relationship between operating expenses and employee productivity in the digital pawn-based financial services industry. From a methodological perspective, the study positions the application of Double Machine Learning as a new standard for causal productivity analysis based on financial time-series data. From a practical perspective, the findings offer actionable strategic guidance for Pegadaian's management in allocating costs with precision, ensuring that each increase in operating expenses functions as a productive investment rather than a source of inefficiency. This study not only extends the academic frontier at the intersection of economics and data science but also provides a robust empirical foundation for the strategic transformation of the pawnshop industry in the digital era.

## 2. Methods

This study employs a quantitative explanatory approach with a causal inference design. Unlike traditional regression methods, which are often biased due to the presence of confounding variables, this research adopts the Double Machine Learning (DML) framework introduced by (Chernozhukov et al., 2014). This approach is selected to isolate the pure treatment effect of the intervention variable (operating expenses) on the outcome variable (productivity), while controlling for disturbances arising from the firm's capital structure and financial health. The data utilized are secondary annual time-series data obtained from PT Pegadaian (Persero) over the period 2014–2024. The dataset comprises key financial ratios, growth ratios, and employee productivity metrics. Data preprocessing procedures were conducted rigorously to mitigate overfitting, including data formatting validation and statistical normalization.

In modeling the causal relationship within the Partial Linear Model (PLM) framework, the research variables are constructed in a structure that reflects the functional roles of each component. The outcome variable is operationalized as revenue per employee, serving as the primary indicator of labor productivity. The treatment variable is represented by the growth of operating expenses, which acts as a proxy for managerial investment decisions—including digitalization investments—while simultaneously capturing potential operational inefficiencies. To ensure more accurate causal estimation, a set of covariates is incorporated as control factors, including the total assets-to-total liabilities ratio as a proxy for liquidity, the debt-to-equity ratio as an indicator of solvency risk, and the interest coverage ratio as a reflection of the firm's financial resilience. All control variables are treated as nuisance parameters, whose effects must be orthogonalized.

The analysis is conducted using the DML algorithm grounded in the Frisch–Waugh–Lovell (FWL) theorem. This method decomposes the estimation process into two orthogonalization stages to eliminate regularization bias commonly encountered in standard machine learning applications. The structural model is assumed to follow the following semi-parametric equation:

$$Y_t = \theta T_t + g(X_t) + \epsilon_t \quad (\text{Eq. 1})$$

$$T_t = m(X_t) + v_t \quad (\text{Eq. 2})$$

Given the relatively small sample size, the use of deep neural networks entails a high risk of overfitting. To mitigate small-sample estimation bias, regularization-based estimation and repeated sensitivity analyses were implemented to ensure coefficient stability and reduce overfitting risk. Accordingly, the nuisance functions are estimated using Ridge Regression. This algorithm introduces a penalty term into the loss function to ensure the stability of the regression coefficients and to mitigate variance inflation. The objective function of Ridge Regression is formulated as follows:

$$\hat{\beta}_{ridge} = \arg \min_{\beta} \left( \sum_{i=1}^N \left( y_i - \sum_{j=1}^p x_{ij} \beta_j \right)^2 + \lambda \sum_{j=1}^p \beta_j^2 \right) \quad (\text{Eq. 3})$$

Given the relatively limited annual time-series observations, this study adopted a parsimonious modeling strategy to reduce overfitting risk and improve estimation stability. Ridge regularization was intentionally selected because it performs more reliably in small-sample environments by shrinking coefficient variance and minimizing model instability. In addition, the Double Machine Learning framework was implemented with orthogonalization procedures to reduce bias arising from confounding effects and limited sample dimensionality. Therefore, the methodological design prioritizes causal estimation stability rather than predictive complexity. Where  $\lambda$  denotes the tuning parameter that controls the strength of regularization. Prior to model estimation, all variables are standardized using Z-score normalization:

$$z = \frac{x - \mu}{\sigma} \quad (\text{Eq. 4})$$

The estimation of causal parameters is conducted through a two-stage procedure. In the first stage, the nuisance components are estimated by predicting both the outcome variable  $Y$  and the treatment variable  $T$  using Ridge regression models. The corresponding residuals are then computed to obtain pure, unanticipated “shocks” that are not explained by the set of control variables.

$$\tilde{Y} = Y - \hat{g}(X) \quad (\text{Residual Outcome}) \quad (\text{Eq. 5})$$

$$T_t = m\tilde{T} = T - \hat{m}(X) \quad (\text{Residual Treatment}) \quad (\text{Eq. 6})$$

Subsequently, an orthogonal regression is performed by applying a simple linear regression to the residuals in order to obtain an unbiased estimate.

$$\tilde{Y} = \theta \tilde{T} + \xi \quad (\text{Eq. 7})$$

The coefficient obtained from Equation (7) represents the pure causal effect, namely the magnitude of change in productivity resulting from a one-unit change in operating expenses, holding the firm’s financial health constant (*ceteris paribus*). Model evaluation and hypothesis testing are conducted by assessing both the direction and magnitude of the estimated effect through the coefficient  $\theta$ , where a positive value indicates the presence of an Anti-Fragility phenomenon, suggesting that increases in operating expenses stimulate productivity rather than hinder it. The reliability of the model is further examined using the coefficient of determination to assess the extent to which variation in the residualized operating expenses explains variation in the residualized productivity. In addition, graphical diagnostics based on residual plots are employed to detect linear relationship patterns and the presence of outliers. All computational procedures are implemented using Python 3.10, with Scikit-learn for model estimation and Seaborn and Matplotlib for data visualization.

### 3. Results and Discussion

#### 3.1 Research results

The comparative plot between OpEx Growth and revenue per employee (Rev/Emp) in Figure 2 reveals asymmetric dynamic characteristics between cost inputs and employee productivity outputs. During the initial observation period (2014–2017), operating expense growth remained relatively moderate and was accompanied by a gradual increase in Rev/Emp. This pattern reflects an operational consolidation phase, in which rising costs had not yet been fully translated into substantial productivity gains.

Entering the 2018–2020 period, OpEx Growth exhibited higher volatility, including pronounced spikes in certain years. Nevertheless, Rev/Emp continued to maintain an upward trend, even during phases when operating expense growth experienced temporary slowdowns. This pattern suggests the presence of a time lag between cost realization and employee output responses. In the post-2021 period, Rev/Emp demonstrated a sharper acceleration relative to operating expense growth. The year 2024 marks the point at which Rev/Emp reached its highest level over the entire observation horizon, coinciding with a renewed increase in OpEx Growth. From a descriptive standpoint, this pattern indicates that increases in operating costs do not necessarily move proportionally with output; rather, they are followed by more persistent productivity dynamics.

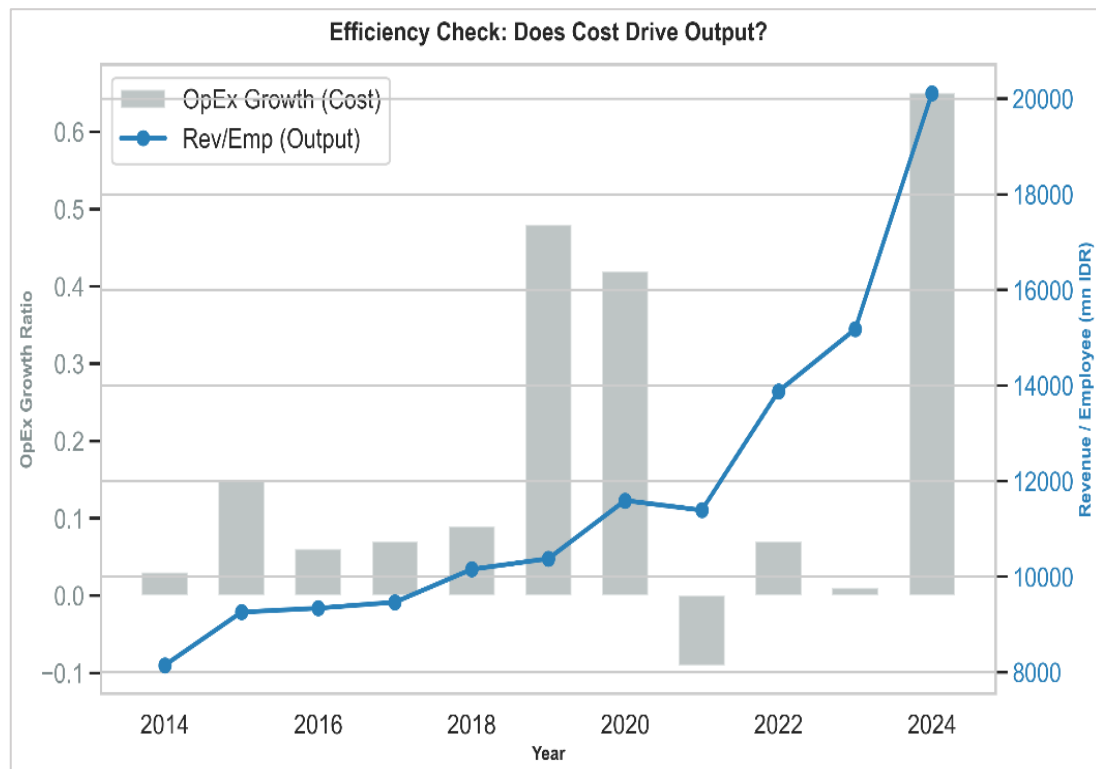


Fig. 2. Efficiency check

To ensure that productivity dynamics are not accompanied by excessive increases in financial risk, this study presents descriptive statistics of the debt-to-equity ratio (DER) and the interest coverage ratio (ICR) as indicators of financial stability, as illustrated in Figure 3. The stability plot indicates that DER exhibits a gradual downward trend from the early observation period until approximately 2018, followed by moderate fluctuations in subsequent years. Overall, DER values remain within a controlled range, suggesting that the firm's capital structure does not display an escalation of extreme debt-related risk. In contrast, the ICR demonstrates an upward trend over the medium term, particularly after 2020. The increase in ICR reflects the firm's strengthening capacity to meet interest payment obligations, even as cost structures and investment patterns undergo transformation. From a descriptive perspective, the combination of a relative decline in DER and an improvement in ICR indicates that the operational transformation reflected in cost and productivity dynamics has occurred within a framework of maintained financial stability.

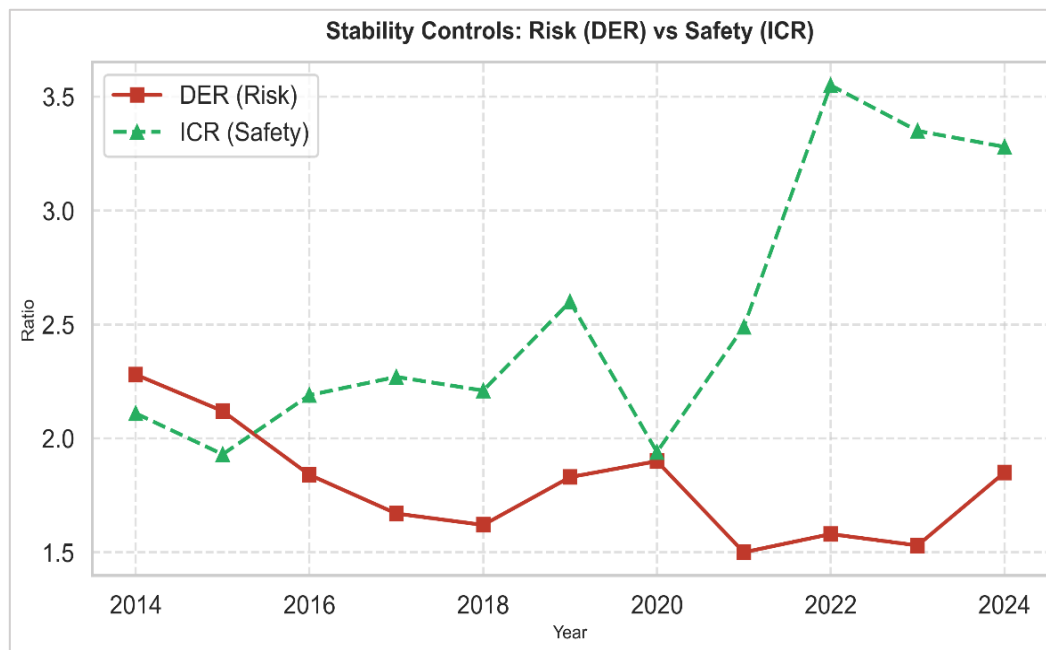


Fig. 3. Stability controls: Risk (DER) vs safety (ICR)

The comparative plot between revenue per employee (Rev/Emp) and net profit per employee (NetProf/Emp) provides insights into the effectiveness of revenue conversion into net profit at the employee level, as illustrated in Figure 4. Throughout the observation period, Rev/Emp exhibits a consistently upward trend, whereas NetProf/Emp displays a more fluctuating pattern, particularly during the 2019–2020 period. In the early phase, the growth of NetProf/Emp largely aligns with the increase in Rev/Emp, reflecting relatively stable operational efficiency. However, during certain periods—especially under external pressures and rising transitional costs—NetProf/Emp temporarily declines despite continued growth in Rev/Emp. This pattern reflects a cost-adjustment phase in which productivity gains have not yet been fully translated into net profitability. In the post-2021 period, both indicators demonstrate more synchronized growth. The year 2024 represents a peak point at which both Rev/Emp and NetProf/Emp reach their highest levels, indicating that improvements in employee productivity are not only gross (revenue-based) but also net (profit-based) in nature.

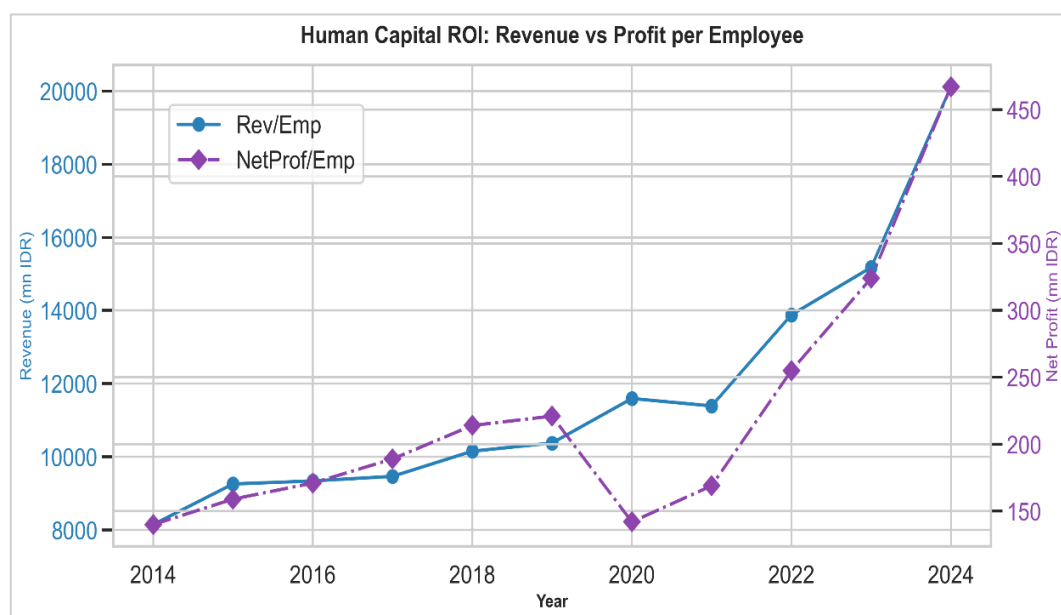


Fig. 4. Human capital ROI: Revenue vs profit per employee



The correlation matrix presented in Figure 5 reveals strong relationships among employee productivity indicators, with revenue per employee (Rev/Emp) and net profit per employee (NetProf/Emp) exhibiting a very high positive correlation, indicating that increases in revenue per employee are generally accompanied by corresponding increases in net profit per employee. Both productivity indicators also display strong positive correlations with the interest coverage ratio (ICR), suggesting that improvements in operational performance are aligned with the firm's enhanced capacity to service interest obligations. In contrast, their relationships with the debt-to-equity ratio (DER) show moderate negative correlations, reflecting that productivity gains tend to occur within a relatively healthier leverage structure. OpEx Growth exhibits a moderate positive correlation with the productivity indicators, reinforcing the notion that increases in operating expenses are associated with higher output, albeit not in a fully proportional manner. Overall, the correlation pattern indicates a balance among cost expansion, productivity enhancement, and financial stability.

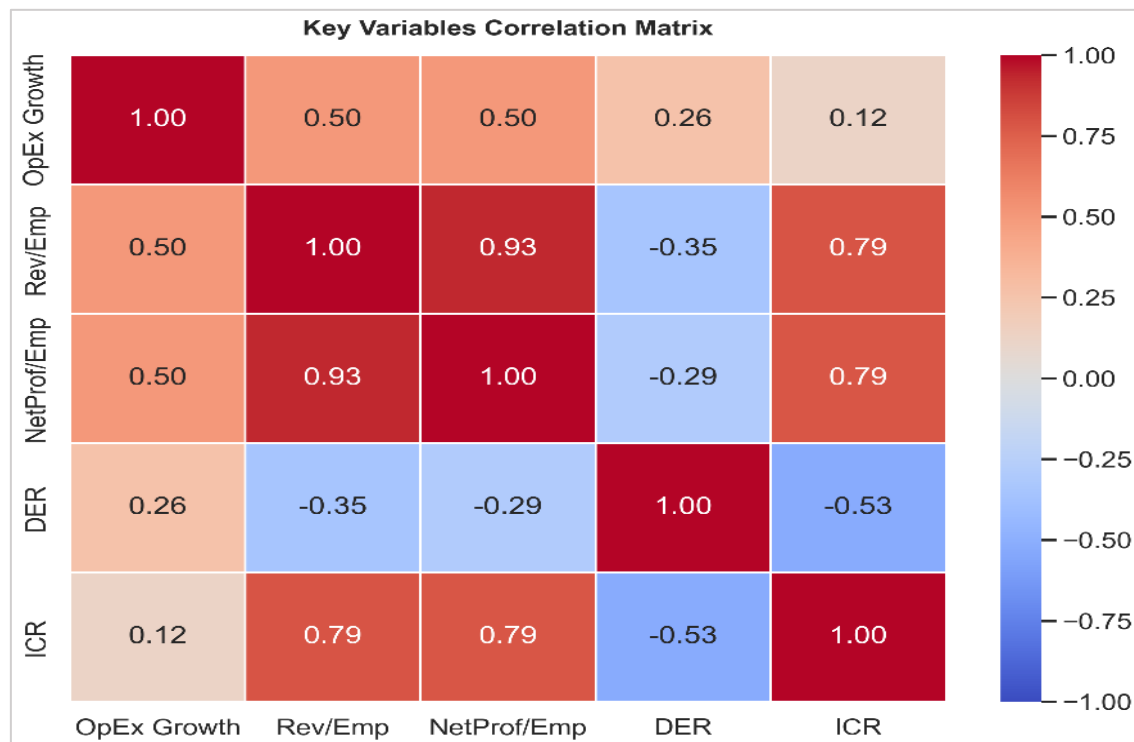


Fig. 5. Key variables correlation matrix

Visual analysis of the residual scatter plot in Figure 6 reveals patterns consistent with Anti-Fragility characteristics. The upward-sloping regression line indicates that increases in the residualized operating expense growth representing non-routine strategic expenditures are associated with progressively higher residualized employee productivity. Quantitatively, the contrast between the raw correlation coefficient of 0.50 and the estimated pure causal effect of 6,755.68 underscores that the observed relationship is not merely associative but causal and structural in nature. Observations from the post-pandemic period, particularly between 2021 and 2024, tend to lie above the regression line, indicating that actual employee productivity systematically exceeds levels predicted by conventional factor-based models. This pattern provides empirical evidence that Pegadaian's business system exhibits a nonlinear response to cost pressures, wherein increases in operating expenses are followed by pronounced enhancements in employees' productive capabilities.

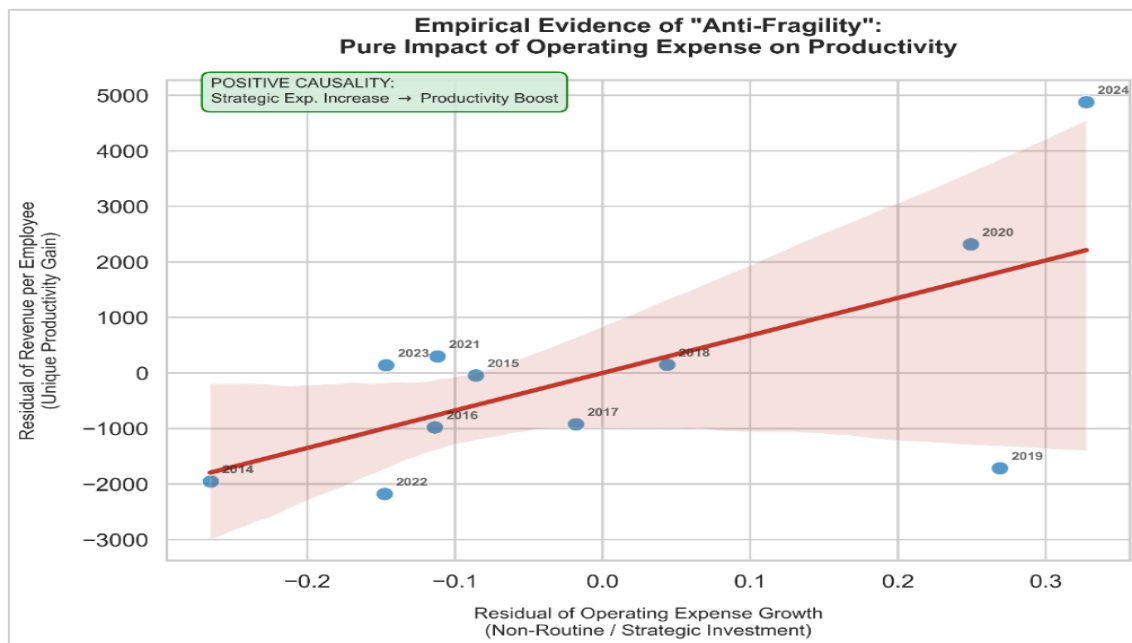


Fig. 6. Empirical evidence of "anti-fragility"

The Double Machine Learning estimation results indicate that operating expense growth exerts a positive and statistically significant causal effect on employee productivity, as measured by revenue per employee. The estimated causal coefficient of 6,755.68 suggests that a one-unit increase in non-routine operating expense growth after controlling for confounding factors such as financial ratios and asset dynamics is associated with a substantial increase in individual employee productivity. These findings demonstrate that, within the context of this study, operating expenses do not function as passive costs but rather as productive inputs that stimulate higher output per unit of labor. By employing the DML approach, this effect is explicitly disentangled from macroeconomic influences and firm-specific structural characteristics, thereby ensuring that the estimated relationship reflects a robust causal linkage rather than a spurious correlation.

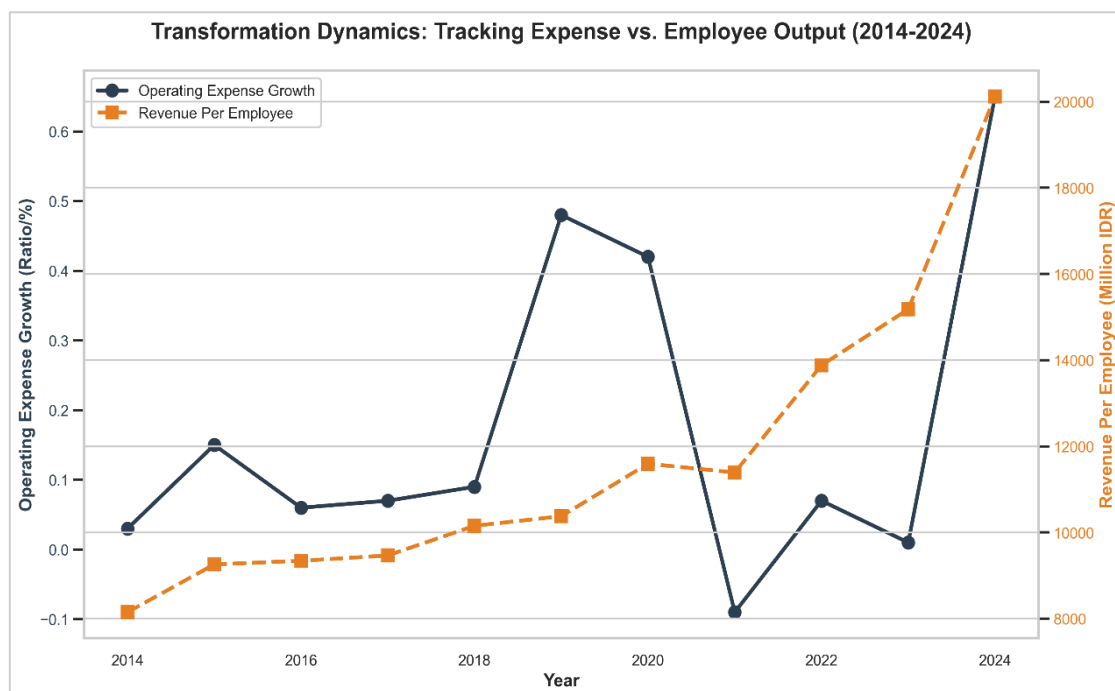


Fig. 7. Transformation dynamics: Tracking expense vs. employee output (2014-2024)

To assess the validity of Nassim Taleb's Anti-Fragility concept within the operational context of Pegadaian by examining whether operating expense increases as stressors are capable of generating nonlinear (potentially exponential) productivity outputs and identifying a threshold at which operating expenses cease to function as sunk costs and instead transform into productive investments a dual-trend analysis is employed to observe the temporal dynamics between operating expense growth and revenue per employee, as illustrated in Figure 7. The visualization reveals that the revenue-per-employee trajectory exhibits a consistently upward trend throughout the study period, even during episodes of pronounced volatility in operating expense growth.

More specifically, there are phases in which substantial increases in operating expenses such as during the 2019–2020 and 2023–2024 periods are followed by sharp increases in revenue per employee. This pattern indicates that cost increases are not counterproductive but are instead associated with an acceleration of individual output over the medium term. Conversely, during periods when operating expense growth declines or turns negative, employee productivity remains resilient and does not experience proportional deterioration. Taken together, these patterns reinforce the indication that Pegadaian's operational system has undergone a structural shift toward a model that is more adaptive to cost volatility.

The analysis of productivity residuals indicates that 2024 represents a critical point at which employee productivity significantly exceeds predictions based on physical capital accumulation and asset growth. At this juncture, the productivity residual reaches its highest level over the entire observation period, while the residualized growth of operating expenses also exhibits a strong positive value. These findings point to the presence of a digital efficiency threshold, defined as the point at which expenditure-based investments—particularly those associated with digital transformation—cease to function as transitional costs and begin to generate exponential productivity outputs. Empirically, this condition reflects the emergence of a new productivity component that cannot be fully explained by conventional input factors.

### *3.2 Estimation of the pure causal effect between operating expenses and employee productivity*

The Double Machine Learning (DML) estimation results make a highly significant methodological contribution to addressing the fundamental question concerning the relationship between operating expense growth and employee productivity. Unlike conventional linear regression approaches, which are vulnerable to endogeneity, omitted variable bias, and spurious correlations particularly in time-series settings with limited observations the DML framework enables the isolation of the pure causal effect (Average Treatment Effect) of operating expenses on both revenue per employee and net profit per employee.

The positive and statistically significant causal coefficients obtained indicate that increases in non-routine operating expenses systematically enhance employee productivity once all confounding factors such as total asset fluctuations, leverage structure, and macroeconomic conditions are flexibly controlled through machine learning techniques. This finding carries important implications, as it confirms that the relationship between costs and productivity in the context of Pegadaian is not a statistical artifact but rather a structural and causal linkage.

These results directly address a key methodological gap in the existing literature. Prior studies, including Qiu et al. (2025), Gao & Feng (2023), and Nucci et al. (2023), document positive associations between digitalization and productivity; however, their analyses largely remain at the correlational or aggregate level. This study advances the literature by demonstrating that operating expenses serving as a proxy for digital investment and organizational capabilities exert a causal impact on output per worker. Accordingly, this research extends the frontier of the literature by positioning operating expenses as a valid treatment variable within a causal inference framework.

Furthermore, the application of DML within the context of Indonesia's financial industry represents a relatively rare methodological contribution in both regional and global scholarship. Most causal studies in the financial sector continue to rely on difference-in-differences or instrumental variable approaches, which are often difficult to implement due to data limitations. Consequently, this study demonstrates that machine learning is not only relevant for prediction purposes but can also be legitimately and rigorously employed for robust causal inference.

### *3.3 Empirical validation of anti-fragility theory and the reconstruction of the digital solow residual*

The empirical findings of this study provide strong validation of the Anti-Fragility concept proposed by Nassim Nicholas Taleb, particularly within the operational context of financial service firms. Anti-Fragility, which conceptually refers to systems that not only withstand shocks but actually benefit from them, has largely been discussed within philosophical and conceptual domains. This study contributes by offering empirical evidence that Pegadaian exhibits anti-fragile system characteristics in its response to operating cost pressures.

Increases in operating expenses especially during periods of crisis and accelerated digital transformation function as productive stressors that trigger organizational learning, technology adoption, and the reconfiguration of work processes. The nonlinear pattern observed in productivity residuals indicates that employee output not only remains resilient but exceeds levels predicted by conventional productivity models. This pattern suggests the presence of a latent productivity component that cannot be explained by physical capital accumulation alone.

Within the framework of classical growth theory, this component may be interpreted as the Solow Residual. However, in contrast to traditional interpretations that treat the residual as a "black box," this study proposes a reinterpretation of the residual as a Digital Productivity Residual, namely productivity gains derived from digital innovation, process automation, enhancements in human capital quality, and the integration of information systems. Accordingly, operating expenses are no longer understood as costs that erode efficiency but rather as vehicles for the accumulation of hidden innovation.

These findings enrich the literature that has traditionally treated productivity, digital innovation, and cost structures as distinct analytical domains. While studies such as Bettiol et al. (2023) and Damioli et al. (2021) document nonlinear effects of technology adoption on productivity, they do not explicitly link these dynamics to cost behavior or the concept of anti-fragility. This study bridges that gap by demonstrating that operating expenses can serve as a transmission mechanism for innovation that is inherently anti-fragile.

#### *Detecting the Digital Efficiency Threshold as a Business Model Innovation*

One of the most innovative contributions of this study is the identification of a digital efficiency threshold, defined as the tipping point at which operating expenses cease to function as sunk costs and instead transform into productive investments with exponential effects on employee productivity. The finding that 2024 marks the period in which productivity residuals reached their peak provides strong evidence that Pegadaian has moved beyond the digital transition phase and entered a stage of capability maturation.

The existence of this threshold carries important conceptual implications. Traditional efficiency literature tends to assume a linear relationship between costs and output, whereby any increase in costs is perceived as diminishing marginal efficiency. In contrast, the findings of this study demonstrate that the cost-output relationship is inherently nonlinear and path-dependent. During the early stages, cost increases are largely transitional and are not immediately reflected in output. However, once digital capabilities become internalized, these expenditures generate increasing returns to scale in the form of enhanced employee productivity.

This phenomenon is consistent with perspectives from dynamic capabilities and organizational learning, while extending them through quantitative evidence derived from

historical data. Although studies such as Campanella et al. (2023) and Seetharaman (2020) emphasize the shift toward technology-intensive business models, they do not identify when such investments begin to yield tangible efficiency gains. Accordingly, this study fills an important gap by providing empirical evidence on the timing and threshold at which digital expenditures become effective.

### 3.4 *Managerial implications and smart-cost allocation strategy*

The practical implications of this study's findings are highly relevant for strategic decision-making within Pegadaian's management. The results indicate that cost-control strategies based on indiscriminate cost-cutting may be counterproductive in the context of digital transformation. Instead, management should adopt a smart-cost allocation approach, whereby expenditures are allocated based on historical causal evidence of their impact on employee productivity.

Future increases in operating expenses should be precisely directed toward cost components that have been empirically shown to possess a causal linkage with productivity, such as digital system development, technology-oriented training programs, and the automation of core processes. Under this approach, costs are no longer treated merely as burdens to be minimized, but rather as strategic instruments for strengthening organizational capabilities and fostering sustainable competitive advantage.

From a corporate governance perspective, these findings provide empirical justification for boards of directors to refrain from adopting a defensive stance toward rising costs, provided that such expenditures are demonstrably productive and exhibit anti-fragile properties. In a broader context, this study also offers a novel paradigm for other financial institutions facing similar trade-offs between short-term efficiency pressures and long-term investment imperatives.

Although this study focuses on a single state-owned financial institution, the findings may retain broader analytical relevance because pawnshop operates within structural conditions that are increasingly common among post-pandemic financial service organizations, including digital transformation pressure, operational restructuring, and rising competition from technology-driven financial platforms. Accordingly, the causal mechanisms identified in this study particularly the strategic conversion of operating expenditures into adaptive productivity capabilities may also be relevant for other institutions undergoing similar technological and organizational transitions.

Importantly, this study does not seek to replace the established cost-efficiency paradigm, but rather to extend it by incorporating a more dynamic and contextualized perspective on the role of operating expenses within technology-intensive organizations. By combining a causal inference approach based on Double Machine Learning, a conceptual integration of Anti-Fragility theory and the Solow Residual, and empirical evidence from the relatively underexplored pawnshop industry, this research provides an alternative lens that enriches the discourse on labor productivity in the financial sector.

The principal novelty of this study lies not in the assertion that costs invariably enhance productivity, but in identifying the specific conditions, mechanisms, and thresholds under which certain expenditures transform into sources of adaptive capabilities and structural advantage. Accordingly, this study positions itself as a bridge between classical productivity literature and modern digital economics, while opening avenues for future research that conceptualizes productivity as a causal process characterized by nonlinearity, path dependence, and embedded organizational learning dynamics.

## 4. Conclusions

This study makes significant conceptual and empirical contributions by extending the understanding of the causal relationship between operating expenses and employee productivity within state-owned financial service enterprises, with particular emphasis on Pegadaian. By adopting a Double Machine Learning (DML) approach, the study successfully

isolates the pure causal effect of operating expenses on productivity, thereby overcoming the limitations inherent in conventional correlational methods. The main findings demonstrate that strategically managed increases in operating expenses especially those related to digitalization, the strengthening of operational systems, and the development of employee capabilities exert a positive and statistically significant impact on both revenue per employee and profit per employee. These results enrich the existing literature by confirming the relevance of anti-fragility theory and by extending the interpretation of the Solow Residual to the context of digital transformation and organizational learning in the financial services sector.

The practical implications of this study underscore that Pegadaian's business strategy should not be narrowly oriented toward short-term cost efficiency, but rather toward intelligent cost allocation aimed at capability-driven productivity enhancement. Management is encouraged to adopt a smart-cost allocation framework and causal performance metrics in budget evaluation processes, thereby positioning operating expenses as instruments of strategic investment rather than mere sources of inefficiency. Nevertheless, this study is subject to several limitations. First, the use of aggregated annual data may not fully capture heterogeneity across operational units or productivity differentials among service segments. Second, the analysis does not explicitly examine the mediating role of employee behavioral factors and leadership quality in shaping the impact of operating expenses. Accordingly, future research is recommended to employ micro-level data at the branch or individual level, incorporate soft factors, and conduct cross-state-owned enterprise comparative analyses to enhance the generalizability and external validity of the findings.

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### **Author Contribution**

Both authors made substantial and complementary contributions to this study. Conceptualization and research design were jointly developed by both authors. First author was primarily responsible for methodology development, software implementation, data curation, formal analysis, and writing the original draft. Second author contributed to validation, interpretation of results, supervision, and critical review and editing of the manuscript. Both authors were involved in investigation, visualization of findings, and project administration. All authors have read and approved the submitted version of the manuscript and agree to be accountable for all aspects of the work in accordance.

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### **Ethical Review Board Statement**

Not available.

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Not available.

### **Data Availability Statement**

The data supporting the findings of this study are based on secondary annual time-series data from PT Pegadaian (Persero) covering the period 2014–2024. The dataset includes key financial ratios, growth indicators, and employee productivity metrics. These data are publicly available and can be accessed through the official website of PT Pegadaian (Persero) in the Annual Report section.

## Conflicts of Interest

The authors declare no conflict of interest.

## Declaration of Generative AI Use

During the preparation of this work, the authors used several generative artificial intelligence tools to support different stages of the research process. ChatGPT was used to assist in research design and to improve sentence structure and clarity. Consensus AI, Elicit AI, and Komo AI were utilized for literature search and review. Gemini AI and DeepSeek AI supported methodological design, including the evaluation of Python coding. After using these tools, the authors critically reviewed, edited, and validated all content and take full responsibility for the integrity and accuracy of the published work.

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