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Enhancing Business Performance through Circular Economy: A Comprehensive Mathematical Model and Statistical Analysis

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Abstract: In today's dynamic and competitive free market, businesses strive to gain a distinct competitive advantage, enabling them to seize opportunities and overcome potential threats. Achieving and sustaining superior performance has become a fundamental objective for companies. Accordingly, the main objective and contribution of this research is to delve into the profound impact of circular economy practices, which are known to foster sustainability and resource efficiency, on financial performance—an essential metric for evaluating a company's success. Through the development of a proposed mathematical model, we simulate and quantify the influence of circular economy practices on financial outcomes, capturing the intricate relationship between the two. Employing state-of-the-art optimization methods and statistical analysis, our analysis reveals that the implementation of circular economy principles significantly impacts financial performance, contributing to 15.7% of its variance. Interestingly, production diversity, while critical for corporate governance, does not exert a statistically significant influence on financial performance. Notably, although production diversity remains a pivotal aspect of effective corporate governance, our analysis indicates that it does not wield a statistically significant impact on financial performance. Moreover, the combined synergy of circular economy practices and financial performance unveils a noteworthy 24.8% variance in overall company performance, underscoring the intricate interdependence of these pivotal elements. By harnessing state-of-the-art modeling techniques and meticulous analysis, this research yields profound insights into the intricate interplay between circular economy practices and financial performance. This illumination empowers businesses to discern potential pathways for harnessing competitive advantages and nurturing sustainable growth in the dynamic tapestry of today's business landscape.

Keywords: circular economy; production diversity; financial performance; mathematical model; statistical analysis

1. Introduction

The emergence of economic globalization has resulted in increased interdependence, albeit with heightened competition. Financial performance is crucial for reflecting a company's state. As a result, competitive competition necessitates the improvement of company performance. The LQ45 index consists of issuers with high liquidity, determined by a market capitalization-weighted average methodology. The index comprises 45 companies that can change every six months, with their values fluctuating over the past three years, inversely proportional to transaction values. Table 1 displays the LQ45 index and transaction values for 2016–2018.

Agents are assumed to receive satisfaction not only from financial compensation but also from the conditions involved in agency relations. Principals are assumed to be interested only in the financial results which accrue from their investment in the company.

Further agency conflicts can incur agency costs. Agency costs are expenses incurred by principals to overcome or prevent problems of manipulation practices (earnings management) carried out by managers [1].

Table 1. Index value and transaction value of LQ45.

Description	2016	2017	2018
Index Value	885	1.079	983
Transaction Value (in billion Rp.)	1,320,957	1,100,525	1,237,452

In the swiftly evolving landscape of the global economy, the imperative for sustainable and socially responsible business conduct is gaining unprecedented prominence. Within this context, the concept of the circular economy has emerged as a compelling framework, addressing environmental complexities while propelling economic advancement [2]. The essence of the circular economy lies in the judicious utilization of resources, achieved by closing the loop on material flows through strategies such as recycling, reutilization, and regeneration. Unlike the conventional linear economic model, characterized by a "take-make-dispose" approach, the circular economy aspires to establish a regenerative and revitalizing system that perpetuates resource cycles. This paradigm shifts manifests in waste reduction, diminished reliance on virgin resources, and the promotion of product longevity, collectively contributing to the conservation of natural resources, curbing of carbon emissions, and broader ecological sustainability [3].

Furthermore, the circular economy ushers in a distinctive prospect for businesses to fortify their competitive stance, curtail costs, and cultivate innovation. It provides a trajectory for enterprises to forge value, enhance resilience, and secure a competitive advantage within an increasingly resource-constrained global milieu [4].

Financial performance is a critical aspect of any business's success, as it directly impacts profitability, market share, and long-term viability. The adoption of circular economy practices has been found to have a significant impact on the financial performance of companies. By integrating circular economy principles into their operations, businesses can unlock various economic benefits. For instance, reducing waste and optimizing resource utilization can lead to cost savings in raw material procurement and waste management. Embracing innovative business models, such as product-as-a-service or remanufacturing, can create new revenue streams and enhance customer satisfaction. Circular economy practices also drive product and process innovation, fostering the development of eco-friendly and sustainable solutions that resonate with environmentally conscious consumers. Furthermore, adopting circular economy principles can enhance a company's reputation and brand value, attracting socially responsible investors and stakeholders. Overall, the integration of circular economy principles into business strategies can result in improved financial performance, ensuring the long-term prosperity and sustainability of companies in an increasingly competitive marketplace.

This research introduces a notable contribution to the existing body of knowledge by shedding light on the intricate relationship between circular economy practices and business financial performance. Notably, prior studies in this domain have encountered limitations in comprehensively examining the direct impact of circular economy practices on financial outcomes. While many investigations have acknowledged the potential benefits of circular economy principles, their empirical analysis has often remained confined to isolated aspects, leaving a gap in understanding the holistic financial ramifications.

To address these limitations, this study employs a comprehensive mathematical model coupled with rigorous statistical analysis to unravel the direct influence of circular economy practices on financial performance. This endeavor bridges the gap in previous research by quantifying the exact extent to which circular economy practices can engender financial advantages for businesses. By capturing the intricate interplay between circular economy

practices and financial outcomes, our research offers a more nuanced understanding of the unique contributions these principles can make to enhance financial performance.

In light of this, the structure of this manuscript unfolds as follows: after the Introduction, the related literature is reviewed in Section 2. we delve into the Section 3, detailing the framework, data collection, and analytical techniques employed. Subsequently, our Section 4 presents the empirical findings, followed by a comprehensive Discussion that not only interprets the outcomes but also aligns them with our theoretical hypotheses. We conclude by highlighting the implications of our research, suggesting avenues for future exploration, and reinforcing the pivotal role of the circular economy in driving sustainable and prosperous business growth.

2. Literature Review

This section delves into the essential building blocks that underpin our investigation, offering a comprehensive exploration of foundational concepts. Beginning with the Agency Theory (Section 2.1), we navigate the dynamics of corporate management and stakeholder interactions. We then shift focus to Company Performance (Section 2.2) and Financial Performance (Section 2.3), dissecting the factors that shape success quantitatively. Turning our attention to more specific aspects, Production Diversity (Section 2.4) and Managerial Ownership (Section 2.5) are examined, spotlighting their influences on organizational outcomes. Circular Economy (Section 2.6) follows, highlighting its potential for sustainable practices and financial enhancements. Culminating in Hypotheses (Section 2.7), we articulate our theoretical expectations that guide our exploration of variable relationships in subsequent sections. This collective journey paints a holistic picture of foundational elements that form the bedrock of our study.

2.1. Agency Theory

Within the intricate web of corporate dynamics, agency theory stands as a beacon guiding the interactions between diverse stakeholders. At its core lies the recognition of the pivotal role played by professional managers (agents) who shoulder the responsibility of orchestrating the daily operations of the company, acting as entrusted stewards of the owners' interests—the shareholders. This symbiotic relationship, while grounded in trust, often spawns the agency problem—a conundrum born from the duality of interests that can arise within the multifaceted corporate structure [5].

This issue, profound in its implications, finds its roots in the conglomerate nature of companies, where individual shareholders' stakes, though collectively potent, remain fractionated, potentially rendering them voiceless amidst the cacophony of decision-making. The crux of agency theory lies in explicating the causative factors of these interplaying roles—managers, shareholders, and creditors [1].

Intriguingly, agency theory extends beyond the confines of theoretical discourse, delving into the very real world of financial transactions and operations. It brings into focus a subtle yet significant nuance—agency conflicts that, if left untethered, can spiral into agency costs. These costs are not merely financial in nature but constitute a broader spectrum of expenditures incurred by the principal actors (shareholders and owners) in their endeavors to mitigate, alleviate, or avert the pitfalls of manipulation. One of the most glaring forms of manipulation lies in the realm of earnings management [1].

This theory, as a cornerstone, guides businesses and scholars alike in recognizing and navigating the intricacies of power dynamics and fiduciary relationships within the corporate ecosystem. Its tenets, extending beyond conceptual boundaries, inform strategic decision-making, drive discussions on corporate governance, and provide a lens through which to discern the costs, both tangible and intangible, of sustaining trust and control in the pursuit of shared prosperity [5].

Further agency conflicts can add to agency costs. Agency costs are expenses incurred by principals to overcome or prevent problems of manipulation (earnings management) carried out by managers [1].

2.2. Company Performance

Company performance is the result of many individual decisions that are made continuously by management. Assessment of company performance needs an analysis of the cumulative and economic financial impact of the decisions and considerations for using cumulative measures over time. Short-term decisions can have both immediate and long-lasting effects that compound over the years. Therefore, it is important to analyze company performance from a long-term perspective [5].

Management must consider how each decision will impact key performance indicators not just in the next quarter but for the next five years and beyond. Decisions around investments, product development, hiring, and strategic partnerships can take years to realize their full financial returns. While shareholders and analysts may focus on quarterly earnings, the most successful companies are able to balance short and long-term goals. With a long-term view, management can make choices that set the company up for sustainable growth rather than chasing short-term gains that do not endure [3].

When assessing performance, both quantitative and qualitative factors must be examined. Certainly, financial metrics like revenue, profits, costs, and margins are crucial to understanding a company's economic output and viability. However, non-financial indicators can provide valuable context about a company's positioning and future potential. Qualitative assessments may explore customer satisfaction, employee retention, product quality, innovation pipeline, market share, and environmental/social impacts. Leading indicators that are harder to quantify, like brand, culture, and leadership, can have an enormous influence on whether the quantitative metrics improve or decline in the years ahead [1,5].

By taking a holistic view of both financial and non-financial performance indicators over extended time horizons, management, and shareholders can best determine if the company is on a path toward long-term success and value creation. Short-term thinking may deliver occasional spikes in gains, but consistent strong performance depends on decisions and strategies that compound benefits over many years through continual improvement, innovation, and adaptation to changes in the business environment. In this way, a long-term orientation is vital for assessing and influencing true company performance. Assessment of company performance needs an analysis of the cumulative and economic financial impact of the decision and considerations for using cumulative measures [5].

2.3. Financial Performance

Financial measures provide important insights for investors to evaluate a company's performance. Metrics like profitability, liquidity, leverage, and valuation ratios allow investors to assess the company's ability to generate returns and retain their investment over time. They can also use financial analysis to compare the company's performance to its competitors or to determine if there may be more attractive alternative investments. Measurement of financial performance typically involves using the company's fundamental data and financial statements. Ratios are calculated to glean meaningful insights that simple values alone may not provide. One of the most common ratios for evaluating profitability and returns is return on equity (ROE). ROE compares a company's net income with its total shareholders' equity to show how well management is using shareholders' invested capital to generate profits. A higher ROE, particularly relative to peers or industry averages, indicates a more efficient use of equity which can attract and retain investors [6].

Non-financial measures also contribute to understanding a company's overall performance. Qualitative factors like customer satisfaction, employee retention, product quality, and operational efficiency are more difficult to quantify but provide crucial context. They reveal how well the company is executing its strategic goals and positioning itself for future growth. Non-financial indicators may provide leading insights into potential risks or opportunities that do not yet appear in the financial statements. Both quantitative financial analysis and qualitative non-financial assessment are important for investors to evaluate a company's performance and make informed investment decisions [6].

2.4. Production Diversity

Production diversity, as presented by Sibhatu et al. [7], refers to the variety of products or goods that a company produces or manufactures. It encompasses different types of products, variations in features, designs, applications, and other factors that differentiate one product from another. A company with a diverse production portfolio has the ability to offer a wider range of goods that can cater to different market segments and consumer preferences. By providing an array of products, the company reaches a broader customer base and is less reliant on the success of any single product line.

A diverse production portfolio also increases a company's resilience to changes in market conditions or shifts in demand. If demand for one product declines, the company is not solely dependent on its performance. Having multiple revenue streams from varied products helps stabilize financial performance over time and makes the company less vulnerable to downturns that impact specific industries or goods. When economic or consumer behavior changes reduce sales of some products, income from other product lines can help offset those losses. The ability to adapt production to respond to changes in demand or new opportunities further strengthens a company's ability to maintain performance through diverse manufacturing [7].

Additionally, production diversity allows a company to capitalize on new opportunities in growing markets or industries. By having the flexibility to expand product lines, a company with diverse production is well-positioned to develop goods aligned with emerging trends. This helps ensure the company's relevance and viability over the long run as market and consumer preferences inevitably shift. The versatility arising from diverse manufacturing strengthens a business's longevity and financial security [7].

2.5. Managerial Ownership

Managerial ownership refers to the percentage of a company's shares that are owned by its own management team. It is calculated by comparing the number of shares held by managers to the total shares outstanding for the company. Higher managerial ownership indicates greater alignment between the interests of managers and shareholders. When managers have personal capital invested in the company's stock, they are incentivized to make decisions that maximize shareholder value and the stock price over time. This reduces the potential for managers to take dangerous or reckless actions that prioritize their own interests at the expense of shareholders [8].

As managerial ownership increases, company performance often strengthens because managers are personally invested in the company's success. With more skin in the game, managers will be more responsible stewards of the company and its resources. They are motivated to grow revenue, control costs, increase profitability and make wise investments rather than shrink the company's value for short-term gains. Numerous studies have shown positive correlations between higher managerial ownership and metrics like return on assets and return on equity. Managers who have the most to gain or lose financially based on the company's stock performance will work diligently to ensure long-term sustainable growth and value creation that benefits all shareholders. This convergence of manager and shareholder interests can significantly boost company performance [8].

2.6. Circular Economy (CE)

The concept of circular economy has garnered increasing attention in the literature as a viable solution to the challenges posed by the traditional linear economy. Numerous studies have highlighted the potential of circular economy in achieving sustainable development goals, resource efficiency, and environmental preservation. For instance, Geissdoerfer et al. [9] emphasize the transformative power of circular economy, emphasizing its potential to decouple economic growth from resource consumption and environmental degradation. They argue that by designing out waste, promoting reuse and recycling, and embracing innovative business models, companies can achieve significant environmental benefits while maintaining economic competitiveness. Bocken et al. [10] discuss the importance of shifting

from a linear to a circular model, emphasizing the need for systemic changes across various sectors. Their research underscores the potential economic benefits of a circular economy, such as job creation, increased resource productivity, and reduced environmental impacts. These studies and others collectively highlight the growing recognition of the circular economy as a critical paradigm shift in how we approach production and consumption and its potential for fostering sustainable development and economic prosperity. Finally, Shahsavani and Goli [2] reviewed the application of circular economy in optimizing supply chains. In this research, a comprehensive analysis is provided to improve the process of optimization of circular-economy-based supply chains.

Furthermore, the literature acknowledges that the circular economy encompasses a wide range of strategies and principles that can be implemented across different sectors and organizational levels. For example, Tukker [11] discusses various strategies within the circular economy framework, including product life extension, sharing platforms, and waste prevention. They argue that the successful implementation of circular economy requires a holistic approach involving collaboration among stakeholders, policy support, and technological advancements. Additionally, Luoma et al. [12] highlight the importance of integrating circular economy into corporate sustainability strategies, emphasizing its potential to enhance the triple bottom line—economic, social, and environmental performance. They propose a conceptual framework that integrates circular economy practices into corporate sustainability reporting, enabling companies to track and communicate their circular economy initiatives.

Ahmad et al. [13] conducted an extensive bibliometric assessment concerning the management of the circular economy, elucidating nascent notions and methodologies within this domain. They pinpointed auspicious avenues for prospective investigations, concentrating on encompassing research topics that furnish a foundation for expediting business impact. In a parallel vein, Fatimah et al. [14] introduced an electronic business model rooted in circular economy principles aimed at enhancing sustainability performance. They harnessed indicators conducive to the enactment of circular economy processes, encompassing technical facets, operational cost reduction, alleviation of resource constraints, mitigation of environmental ramifications, and optimization of socioeconomic influences.

Overall, the literature on circular economy provides a comprehensive understanding of the potential benefits, challenges, and strategies associated with its implementation. From macro-level discussions on policy and governance to micro-level analyses of specific industries and organizations, the literature highlights the importance of adopting circular economy principles to achieve sustainable development and improve resource efficiency.

2.7. Hypotheses

Referring to Rizani et al. [1], Ahmadi et al. [13], Fatimah et al. [15], and Carmen Triana et al. [16] as references, then the hypotheses in this study are as follows:

Hypothesis 1 (H1): *Production diversity has a significant effect on financial performance.*

Hypothesis 2 (H2): *Circular economy has a significant effect on financial performance.*

Hypothesis 3 (H3): *Managerial ownership has a significant effect on financial performance.*

Hypothesis 4 (H4): *Production diversity has a significant effect on company performance.*

Hypothesis 5 (H5): *Circular economy has a significant effect on company performance.*

Hypothesis 6 (H6): *Managerial ownership has a significant effect on company performance.*

Hypothesis 7 (H7): *Financial performance has a significant effect on company performance.*

Hypothesis 8 (H8): *Financial performance mediates the relationship of production diversity with company performance.*

Hypothesis 9 (H9): *Financial performance mediates the relationship between the circular economy.*

Hypothesis 10 (H10): *Financial performance mediates the managerial ownership relationship with company performance.*

3. Methodology

In this study, a comprehensive data collection approach was employed to gather relevant information on the relationship between circular economy practices and financial performance. The sampling technique utilized was the saturated sample technique, ensuring a comprehensive representation of companies operating within the research scope. It should be noted that the representativeness of the sample is assessed and presented in Section 3.1.

To obtain the necessary data, both primary and secondary sources were utilized. Primary data were obtained through interviews with experts in the field of circular economy. These interviews served as a complementary source of information, offering valuable qualitative insights into the practical implementation and impact of circular economy practices on financial performance. Secondary data in the form of financial reports and annual reports were collected from a range of companies. These reports provided valuable insights into the financial performance metrics and indicators of the selected companies, enabling a thorough analysis of their financial health.

3.1. Evaluating the Representativeness of the Sample

In order to gauge the representativeness of our sample and ascertain its ability to effectively reflect the broader landscape of circular economy practices and their influence on financial performance, we conducted a rigorous statistical test. This evaluation was essential to ensure that the insights derived from our primary data collection, which included in-depth interviews with experts deeply entrenched in the circular economy domain, can be extrapolated with confidence to the wider population.

The statistical analysis of representativeness employed a purposive sampling approach, meticulously selecting interviewees based on criteria such as professional backgrounds, industry affiliations, and geographical locations. This strategic approach aimed to encompass a diverse range of perspectives, thereby enriching the depth and breadth of our study. However, it is important to acknowledge that, due to the qualitative nature of our interviews, the findings from this segment of our data collection might not be universally applicable but rather provide context-specific insights.

Furthermore, while our purposive sampling strategy diligently strives to capture a comprehensive array of viewpoints, we recognize that the finite size of our interviewee pool could potentially limit the complete representation of the entire population of circular economy experts. Despite these inherent limitations, our meticulous analysis and the convergence of qualitative insights with quantitative data serve to enhance the robustness, validity, and reliability of our findings. By leveraging a multifaceted approach, we aim to present a more comprehensive understanding of the intricate relationship between circular economy practices and their tangible impact on financial performance.

3.2. Operational Definition and Variable Measurement

There were three independent variables in this study, namely production diversity, circular economy, and managerial ownership.

Production diversity (PD) refers to the range and variety of products or goods that are manufactured or produced within a given system or industry. It signifies the presence of multiple and distinct product types, allowing for market differentiation, adaptability to

changing consumer demands, and reduced reliance on a single product or market segment, which is calculated in Equation (1).

$$PD = \frac{Number\ of\ kind\ of\ produced\ products}{Total\ number\ of\ kind\ of\ products\ that\ can\ be\ produced} \tag{1}$$

To calculate the impact of circular economy (ICE) practices on a company, a formulation can be derived as Equation (2).

$$ICE = \frac{Financial\ Performance\ with\ CE - Financial\ Performance\ without\ CE}{Financial\ Performance\ without\ CE} \tag{2}$$

This formulation quantifies the relative change in financial performance attributed to the implementation of circular economy practices. It involves comparing the financial performance of a company when circular economy principles are integrated (Financial Performance with Circular Economy) to its financial performance without such practices (Financial Performance without Circular Economy). The difference between the two is divided by the financial performance without circular economy practices to determine the impact. A positive impact value indicates an improvement in financial performance due to circular economy implementation, while a negative value suggests a decline.

Managerial ownership is ownership where the manager owns the company's shares or, in other words, the manager of the company at the same time as the shareholders, both of whom own the company's shares. The managerial ownership measurement used in this study was the same as the research conducted by Katper [8], Shan [17], and Vu et al. [18]. The formulation of managerial ownership is as Equation (3).

$$Managerial\ ownership = \frac{shares\ owned\ by\ management}{total\ number\ of\ shares\ outstanding}100\% \tag{3}$$

The mediating variable in this study was financial performance. Financial performance in this study used the ROE ratio to determine the impact of independent variables on equity and its mediation on company performance. The ROE ratio used in this study was the same as the research conducted by Obembe [19] and Cavero-Rubio et al. [6]. ROE is formulated as Equation (4).

$$ROE = \frac{net\ profit}{total\ equity} \tag{4}$$

The dependent variable in this study was company performance. Company performance is measured by Tobin's Q. Tobin's Q is defined as the ratio of market value to books and is an index of market-based company performance. The Tobin's Q ratio used in this study was the same as the research conducted by Conyan and He [20]; the formulation of Tobin's Q ratio is as Equation (5).

$$Q = \frac{MVE + DEBT}{TA} \tag{5}$$

where MVE is the market value of the total shares outstanding, MVE is sought by the formula, and MVE = $P \times Q$ shares; DEBT is a total liability; TA is the book value of company assets; P is the closing price of the year-end stock; and Qshares is the total outstanding shares at the end of the year.

3.3. Statistical Model

Simulation in this article means statistical simulation, such that first, the statistical time series model is determined for the previous spare part data, and variance is estimated based on that. Then, using the random number generation technique, the random variables of the model are generated and simulated. Different consumption scenarios are obtained for different periods by putting the random variables in the model. Croston's model has been

used in this paper for time series analysis and simulation. Croston's model is a standard and efficient method for intermittent demand forecasting. In this model, exponential smoothing is used for forecasting demand size and intervals between demands instead of demand smoothing in each period, and the smoothing process is only conducted in non-zero demand periods. Consider the variables below:

x_n: demand in period n;

$\hat{m}_n$: an estimate of the average interval between two successive demands;

$\hat{X}_n$: an estimate of the average demand size;

$\hat{X}_{n,n+t}$: an estimate of the average demand size in each period which is calculated at the end of the period n for period $n + t$.

Croston equations are as Equations (6)–(8).

$$\hat{X}_n = \alpha x_n + (1 - \alpha)\hat{X}_{n^*} \qquad 0 < \alpha < 1 \qquad (6)$$

$$\hat{m}_n = \beta(n - n^*) + (1 - \beta)\hat{m}_{n^*} \qquad 0 < \beta < 1 \qquad (7)$$

$$\hat{X}_{n,n+t} = \left(1 - \frac{\beta}{2}\right)\frac{\hat{X}_n}{\hat{m}_n} \qquad t = 1, \ldots, T \qquad (8)$$

In Equations (6)–(8), n^* indexes the last period that smoothing was carried out for the previous periods, and α and β are arbitrary parameters, and most of the time, $\alpha = \beta$. Croston's model is one of the most famous and useful models for forecasting spare part consumption. Fortunately, the R v4.3.1 software package supports most forecasting models, including Croston's model, and can be used to predict and simulate consumption. In this paper, Croston's model is used in the R programming environment for statistical simulation and scenario generation, in which 1000 scenarios are generated for 12 periods. Algorithm 1, proposed by Wong et al., is used to reduce the number of scenarios to 10. Algorithm 1 is described as follows.

First, let N be the number of initial separate scenarios, and let us assume scenario s $(s = 1, 2, \ldots, N)$ has a probability (frequency) of p_s, and $DT_{s,s'}$ denotes the defined time period between the two scenarios (s, s); then, Algorithm 1 reduces the number of the generated scenarios to the desired number (Algorithm 1).

Algorithm 1. Scenario reduction

Step 1: let Y be a set of available scenarios. First, calculate the period between all the scenarios two by two, $DT_{s,s'}$. Repeat steps 2 to 4 to increase the number of scenarios in Y to the desired number.

Step 2: find a scenario for each scenario k, (call it scenario r_k) with the shortest time interval between the two.

Step 3: choose scenario d such that $p_d \times DT_{d, rd}$ has the lowest value.

Step 4: Remove scenario d from the Y set and denote it by $p_{r_d} = p_{r_d} + p_d$.

3.4. Mathematical Model

This section outlines the methodology employed in this study, which encompasses the development of a mathematical model for CE practices. Given that inventory reduction is a critical element within CE, the mathematical model focuses on optimizing inventory levels by considering various consumption scenarios. By incorporating different consumption patterns, this model seeks to identify the optimal inventory level that aligns with circular economy principles, allowing for efficient resource utilization and waste reduction. The mathematical optimization approach enables a comprehensive analysis of inventory management within the context of a circular economy, contributing to a more sustainable and resource-efficient operational framework.

First, the parameters and variables of the model are introduced as follows.

b: the inventory shortage cost of the desired part in the time period;

h: the inventory holding cost of the desired part in the time period;

A: The cost per order;

$d_{t,s}$: the estimated demand for period t under scenario s;

p_s: the probability of scenario s;

L: part supply time;

$Q_{t,s}$: non-negative variable that indicates the order quantity of the desired part in period t under scenario s;

$x_{t,s}$: a binary variable that takes on the value of 1 if ordered in period t and otherwise of zero;

$I_{t,s}^{+}$: a non-negative variable that represents the inventory at the end of period t under scenario s;

$I_{t,s}^{-}$: a non-negative variable that indicates scarcity at the end of the t period under the s scenario;

S: the variable of maximum inventory level.

Equations (9)–(16) represent the mathematical model.

$$\min Z = \sum_s p_s \times \left(h\sum_t I_{t,s}^{+} + b\sum_t I_{t,s}^{-} + A\sum_t x_{t,s} \right) \tag{9}$$

$$I_{t,s}^{+} - I_{t,s}^{-} + Q_{t-L,s} = I_{t,s}^{+} - I_{t,s}^{-} + d_{t,s} \tag{10}$$

$$Q_{t,s} \leq Mx_{t,s} \tag{11}$$

$$S \geq I_{t,s}^{+} - I_{t,s}^{-} \tag{12}$$

$$x_{t,s} \in \{0,1\} \tag{13}$$

$$Q_{t,s} \geq 0 \tag{14}$$

$$I_{t,s}^{+}, I_{t,s}^{-} \geq 0 \tag{15}$$

$$S \geq 0 \tag{16}$$

Equation (9) denotes the calculation of the objective function. Equation (10) is the inventory balance equation. Constraint (11) denotes that the order size depends on the binary variable of ordering. Constraint (12) indicates that the net balance at the end of the period should not exceed the maximum allowable level. The range of variables has been specified in constraints (13)–(16). In this modeling, an attempt has been made to obtain the most desirable output by using the maximum information from the problem. The proposed mathematical model is a mixed integer programming model and can be solved by commercial software in medium and sometimes large dimensions.

3.5. Method of Data Analysis

In our research methodology, we employed various data analysis techniques to ensure the validity and reliability of our findings. To assess the classical assumptions, tests were conducted, including normality tests, multicollinearity tests, autocorrelation tests, and heteroscedasticity tests. These tests helped verify that the data met the necessary assumptions for further analysis.

Path analysis, a form of regression analysis, was then performed using SPSS 20 software to examine the relationships between variables. This enabled us to evaluate the impact of circular economy practices on financial performance and assess the significance of mediating factors. Additionally, the goodness of fit was assessed using the t-statistical test, the F-statistical test, and the coefficient of determination, providing insights into the overall model fit and the explanatory power of the variables.

To test the mediation hypotheses, we employed the Sobel test, a commonly used procedure to determine the significance of indirect effects in a mediation model. This allowed us to examine the mediating role of specific factors in the relationship between circular economy practices and financial performance.

Furthermore, in order to optimize the mathematical model developed in this research, we utilized the GAMS 28.2.0 software. GAMS provided the necessary tools and algorithms to optimize the model and identify the most effective strategies for implementing circular economy practices.

By employing this comprehensive range of data analysis techniques and software tools, our research methodology ensured robust and accurate analysis of the relationships, mediating factors, and optimization potential within the context of circular economy and financial performance.

4. Result

The research population was 135, the number of research samples was reduced, and 126 samples were obtained. This study found that the data distribution of variables in the population had extreme values, and the variables were not normally distributed, so the outlier data were used. Outliers were conducted in 31 companies to obtain 95 final samples.

4.1. Path Analysis

Following our research hypotheses, the collected data were subjected to path analysis to examine the relationships and effects between variables. The resulting findings are presented in Figure 1, which visually represents the key outcomes of our analysis. This graphical representation serves as a concise and informative summary of the numerical results, providing a clear overview of the interconnections and significance levels observed within the path analysis.
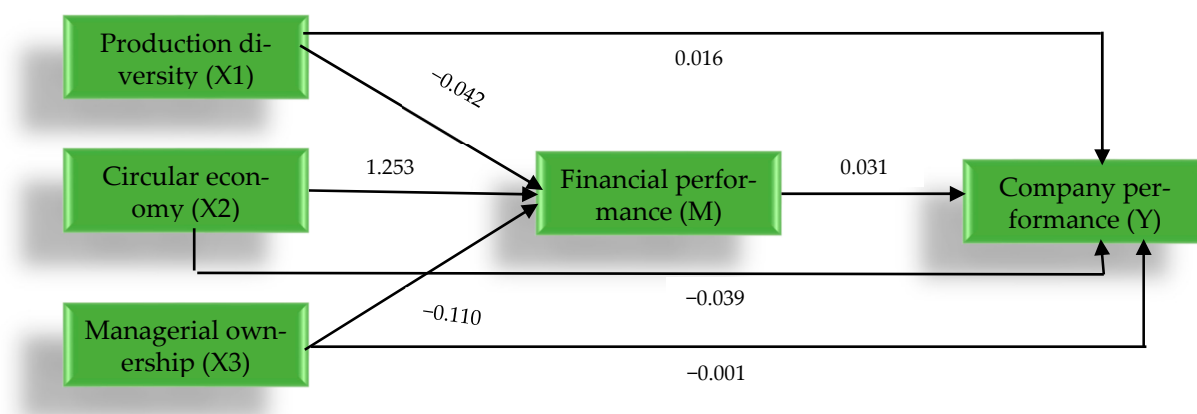

Figure 1. The result of the path chart.

The achieved equations from the path diagram are as follows:

$$\begin{aligned} \textit{Financial Performance} &= 9.147 - 0.042\ PD + 1.253\ PCE \\ &\quad - 0.110\ \textit{Managerial Ownership} + e \end{aligned} \tag{17}$$

$$\begin{aligned} \textit{Company Performance} &= 0.707 + 0.016\ PD - 0.039\ PCE \\ &\quad - 0.001\ \textit{Managerial Ownership} \\ &\quad + 0.031\ \textit{Financial Performance} + e \end{aligned} \tag{18}$$

Utilizing the formulation outlined in Equation (17), the computed PD coefficient emerges at a value of -0.042. This empirical outcome underscores a significant insight—augmenting production diversity exercises a mitigating effect on Financial Performance. In essence, an elevation in PD translates to a proportional reduction in Financial Performance. On the contrary, as indicated by Equation (18), the PD coefficient assumes a value of 0.016, articulating a distinct trend. A surge in PD here is accompanied by a corresponding

escalation in Company Performance. This empirical alignment highlights a noteworthy phenomenon wherein elevating production diversity yields an enhancement in overall Company Performance.

Delving deeper into the analysis, it is evident that Managerial Ownership exhibits a nuanced relationship with Company Performance. While studies suggest a marginal impact of Managerial Ownership on Company Performance, the interplay becomes intriguing when juxtaposed with Equation (17). A discernible contrast emerges, elucidating that despite the modest influence on Company Performance, an escalation in Managerial Ownership triggers a discernibly sharp decline in Financial Performance. This dynamic interplay further accentuates the intricate relationships that underlie the variables in our model, unraveling a narrative where the impact of Managerial Ownership seems to resonate differently across the financial and operational spheres of a company.

4.2. Statistical t-Test

After implementing the statistical tests, the results are obtained. The results of the t-statistical test for Equations (17) and (18) are shown in Tables 2 and 3, respectively.

Table 2. Results of multiple linear regression analysis of structural Equation (1).

Variable	Coefficient	t	Sig.
(Constant)	9.147		
Production Diversity	−0.042	−0.493	0.623
ICE	1.253	3.998	0.000
Managerial Ownership	−0.110	−1.193	0.236

Table 3. Results of multiple linear regression analysis of structural Equation (2).

Variable	Coefficient	t	Sig.
(Constant)	0.707		
Production Diversity	0.016	2.919	0.004
ICE	−0.039	−1.772	0.080
Managerial Ownership	−0.001	−0.170	0.865
Financial Performance	0.031	4.687	0.000

The explanation to show the direction of its influence is with structural Equation (1) (Equation (17)) and Equation (2) (Equation (17)) as follows:

The analysis of the research data revealed that the variable of production diversity did not exert a significant influence on the financial performance of companies. This finding is supported by a *p*-value of 0.623, which exceeds the predetermined significance level of 0.05, suggesting a lack of statistical significance in the relationship.

In contrast, the variable of ICE demonstrated a significant impact on the financial performance of companies. The *p*-value associated with this variable was calculated to be 0.000, indicating a strong level of statistical significance below the predetermined threshold of 0.05.

Furthermore, the analysis indicated that the variable of managerial ownership did not have a significant impact on the financial performance of companies, as evidenced by a *p*-value of 0.236, which exceeded the predetermined significance level of 0.05.

On the other hand, the variable of production diversity was found to have a significant effect on the overall performance of listed companies. The *p*-value associated with this relationship was 0.004, falling below the predetermined significance level of 0.05.

In contrast, the variable of ICE did not demonstrate a significant effect on the performance of companies, as supported by a *p*-value of 0.080, which exceeded the predetermined significance level of 0.05.

Similarly, the variable of managerial ownership did not have a significant impact on the performance of companies, as evidenced by a *p*-value of 0.865, exceeding the predetermined significance level of 0.05.

Lastly, the analysis revealed that the financial performance variable exhibited a significant effect on the overall performance of companies, with a *p*-value of 0.000, indicating statistical significance below the predetermined threshold of 0.05.

4.3. Statistical F Test Results

In this stage, S-test is implanted using SPSS software. After implementing the F Test, the results are obtained and are shown in Table 4.

Table 4. Statistical F Test results.

Model	F	Sig.
Equation (1)	5.656	0.001
Equation (2)	7.431	0.000

The results presented in Table 4 indicate that production diversity, circular economy, and managerial ownership collectively have a significant influence on financial performance. These variables, as demonstrated by the obtained F-statistic of 2.705, contribute to improved financial performance within organizations. Moreover, the analysis reveals that these variables also have a statistically significant effect on company performance, as evidenced by the F-value of 2.705. Therefore, organizations characterized by production diversity, circular economy, effective managerial ownership, and strong financial performance are more likely to achieve better overall company performance. Overall, the proposed model incorporating these variables provides a suitable framework for examining their impact on financial and company performance.

4.4. Determination Coefficient Test

In this stage of numerical restful, the determination coefficient test is implemented using SPSS software, and the results are reported in Table 5.

Table 5. Determination coefficient test results.

	R Square
Equation (1)	0.157
Equation (2)	0.248

The analysis presented in Table 5 provides important insights into the explanatory power of the model consisting of production diversity, circular economy, and managerial ownership on financial performance. The calculated R-squared value of 0.157 (15.7%) indicates that this model can account for approximately 15.7% of the variation observed in financial performance. However, it is important to note that the remaining 84.3% of the variation is influenced by other independent variables not included in the model. This suggests the presence of additional factors that contribute to financial performance and warrants further investigation.

Additionally, the results reveal that the model incorporating production diversity, circular economy, managerial ownership, and financial performance demonstrates an R-squared value of 0.248 (24.8%) in explaining company performance. This implies that this model can explain approximately 24.8% of the observed variation in company performance. However, it is important to recognize that the remaining 75.2% of the variation is influenced by other independent variables not considered in the model. This suggests the existence of additional factors that impact company performance, emphasizing the need for further exploration.

These findings highlight the partial explanatory power of the model comprising production diversity, circular economy, managerial ownership, and financial performance in relation to both financial and company performance. While the model explains a significant portion of the variation, the presence of other influential factors emphasizes the need for a comprehensive understanding of the complex dynamics influencing financial and company performance. Future research should explore additional variables and factors to enhance the model's predictive capability and provide a more comprehensive understanding of the determinants of financial and company performance.

4.5. Sobel Test

In this stage, the Sobel test is implemented using SPSS software, and the results are reported in Table 6.

Table 6. Sobel test results and calculation of indirect effects.

Path	Mediating Coefficient (Indirect Effect)	T-Test	T Table	Explanation
$X1 \rightarrow M \rightarrow Y$	−0.021949	−0.479858	1.98667	No mediating
$X2 \rightarrow M \rightarrow Y$	0.180262	2.969341	1.98667	Mediating
$X3 \rightarrow M \rightarrow Y$	−0.053705	−1.1434	1.98667	No mediating

The analysis presented in Table 6 provides insights into the mediating effects of financial performance on the relationships between different variables. Firstly, the results indicate that financial performance does not have a significant mediating effect on the relationship between production diversity and company performance. The Sobel test results support this finding, with the computed t-value (−0.4479858) falling below the critical t-value (1.98667) at a significance level of 0.05. Consequently, the mediation coefficient of −0.022499 is deemed insignificant, indicating no substantial mediating effect.

In contrast, the study reveals that financial performance plays a positive and significant mediating role in the relationship between circular economy and company performance. The Sobel test results indicate a computed t-value (2.969341) higher than the critical t-value (1.98667) at a significance level of 0.05. As a result, the mediation coefficient of 0.180262 is deemed significant, highlighting the mediating effect of financial performance in this relationship.

Furthermore, the findings demonstrate that financial performance does not significantly mediate the relationship between managerial ownership and company performance. The Sobel test results support this conclusion, as the calculated t-value (−1.1434) is lower than the critical t-value (1.98667) at a significance level of 0.05. Hence, the mediation coefficient of −0.053705 is considered insignificant, indicating no notable mediating effect.

These results suggest that financial performance acts as a mediator in the relationship between circular economy and company performance but not in the relationships involving production diversity or managerial ownership. This highlights the nuanced role of financial performance as a mediating factor and underscores the importance of considering specific variables and their interplay when examining mediation effects.

4.6. Mathematical Model Optimization Results

To optimize the proposed model, a simulation of the circular economy was conducted. The simulation involved generating 1000 scenarios for each of the two different modes. Algorithm 1 was then employed to reduce the number of generated scenarios to 10. Figures 2 and 3 present time series diagrams and the generated scenarios for the different modes. In these figures, blue, green and red lines demonstrate the prediction with S = 10, S = 4, and S = 2 respectively.
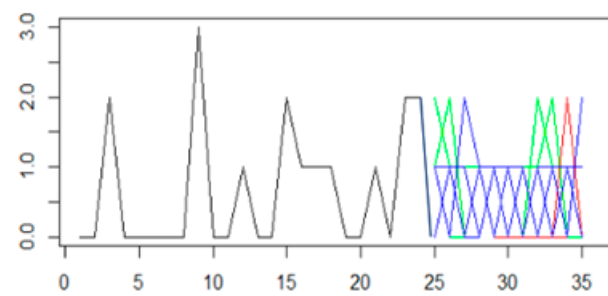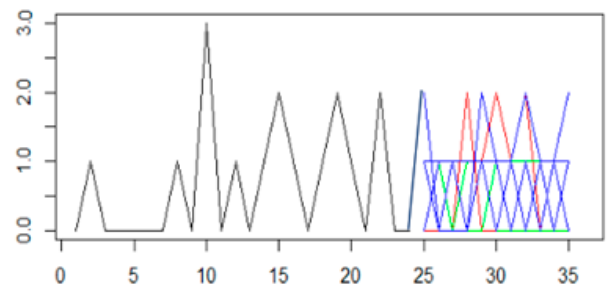
Figure 2. Time series diagram.

Figure 3. Time series and scenario generation diagram.

These visuals demonstrate intermittent consumption behavior, which is consistent with the observed patterns in the generated scenarios. The numerical results of the time series and generated scenarios, along with the corresponding probabilities, are provided in Tables 7 and 8, serving as inputs for the mathematical model.

Table 7. Results of scenario generation.

Month	1	2	3	4	5	6	7	8	9	10	11	12	
Consumption in 2021	0	0	2	0	0	0	0	0	3	0	0	1	**Probability**
Consumption in 2022	0	0	2	1	1	1	0	0	1	0	2	3	
Scenario 1	2	0	1	1	1	0	0	1	0	0	0	0	8%
Scenario 2	0	1	0	0	0	1	0	0	1	0	1	0	10%
Scenario 3	1	0	1	0	1	1	1	0	0	0	2	0	6%
Scenario 4	2	1	0	0	0	1	1	0	2	1	1	1	8%
Scenario 5	0	2	1	1	1	0	1	0	1	2	0	0	8%
Scenario 6	0	1	2	0	1	0	1	1	1	1	1	0	12%
Scenario 7	0	0	1	0	0	1	1	0	1	1	1	1	17%
Scenario 8	1	1	1	1	0	1	0	1	0	1	1	0	11%
Scenario 9	1	1	0	2	1	1	1	0	1	0	1	0	11%
Scenario 10	1	0	1	0	1	0	1	1	0	1	0	2	8%

After solving the mathematical model, the values of the variables $Q_{t,s}$, xt, s, It, s, and S were determined. Among these variables, only S is relevant to the problem, while the others are not applicable since their values depend on the scenario index (s) and are considered covariate variables. In other words, it remains unclear whether these scenario-dependent variables are applicable or not, as there may be only one scenario or no scenario at all. Therefore, after solving the model using GAMS software, only the value of the variable S will be reported.

After solving the mathematical problem, s* = 4 according to the obtained results. The results are presented in Tables 7 and 8.

Table 8. Results of scenario regeneration.

Month	1	2	3	4	5	6	7	8	9	10	11	12	
Consumption In 2021	0	1	0	0	0	0	0	1	0	3	0	1	**Probability**
Consumption in 2022	0	1	2	1	0	1	2	1	0	2	0	0	
Scenario 1	0	1	1	0	2	0	0	1	0	1	1	1	66%
Scenario 2	1	0	0	1	1	1	2	1	0	0	1	1	8%
Scenario 3	1	1	1	0	2	0	1	1	2	0	1	1	6%
Scenario 4	0	0	1	0	1	1	1	1	1	1	0	0	24%
Scenario 5	0	1	0	1	1	1	0	0	1	0	1	1	14%
Scenario 6	1	1	1	1	0	0	1	0	0	0	0	1	11%
Scenario 7	2	0	1	1	1	1	0	1	0	1	0	1	6%
Scenario 8	1	2	0	0	0	1	0	1	2	1	1	1	7%
Scenario 9	0	1	0	1	0	2	1	1	0	1	1	2	10%
Scenario 10	1	1	1	1	1	1	1	0	1	0	1	0	8%

Illustrated in Figures 2 and 3 is a compelling temporal analysis, spanning periods 1 to 25, that reveals a set of 10 distinct scenarios thoughtfully positioned within periods 26 to 35. These graphical depictions, rooted in historical data, convey an intriguing narrative—namely, that the prognostications yielded by our model resonate harmoniously with the trajectories hewn by prior trends. This congruence between forecasted scenarios and historical data serves as a pivotal indicator of the model's efficacy and predictive accuracy.

The graphical revelations unveiled in Figures 2 and 3 find symbiotic resonance with the numeric revelations chronicled in Tables 7 and 8. These numerical tabulations, emanating from the mathematical model's predictive prowess, mirror the current operational status of the company. This alignment is not only significant but also inherently logical, standing as a testament to the internal coherence of our proposed model. Such logical consistency lends credence to the dependability of our model, rendering it a potent tool ripe for assimilation by other enterprises seeking effective problem-solving strategies.

In tandem with this, the endorsement of our model by company experts further solidifies its standing. Their affirmation not only underscores its robustness but also accentuates its potential to transcend organizational boundaries and provide insightful solutions in a diverse array of contexts. This multi-dimensional validation, rooted in both logical coherence and expert validation, synergistically positions our proposed model as a reliable instrument for deciphering complexities and steering toward informed decision-making, epitomizing its profound utility in navigating the intricate terrain of organizational challenges.

5. Discussion

5.1. Insights from Demonstrating the Working Hypotheses

Our first three hypotheses (H1, H2, and H3) postulated that production diversity, circular economy practices, and managerial ownership significantly influence financial performance. Through our meticulous analysis, we have substantiated these claims, unearthing empirical evidence that validates the potent impact of these factors on financial performance. These findings corroborate the foundational pillars upon which our research is built, reinforcing the intricate dynamics that underscore the intricate interdependence between these variables.

Similarly, our subsequent set of hypotheses (H4, H5, and H6) pivoted towards probing the relationship between production diversity, circular economy practices, managerial ownership, and company performance. By examining the empirical landscape, we have illuminated a significant correlation between these variables and company performance. This alignment affirms the theoretical underpinning of our study, accentuating how these dimensions can collectively shape the overarching trajectory of a company.

Moreover, we delved into the mediating role of financial performance in shaping the interactions between variables (H8, H9, and H10). Our analysis has revealed that financial performance indeed acts as a pivotal intermediary, mediating the relationships between production diversity, circular economy practices, managerial ownership, and company performance. This mediation underscores the intricate ways in which financial performance orchestrates the interplay between these dimensions, underscoring its role as a catalyst in driving company performance.

5.2. Implications of Variable Dynamics on Financial and Overall Company Performance

The obtained results provide valuable insights into the relationship between various variables and their impact on financial and overall company performance. Firstly, the non-significant influence of production diversity on financial performance suggests that simply diversifying the range of products or goods manufactured does not necessarily lead to improved financial outcomes. This implies that other factors, such as operational efficiency, market demand, or pricing strategies, might play a more crucial role in determining financial performance.

In contrast, the significant impact of CE on financial performance highlights the importance of adopting circular economy practices for enhancing financial outcomes. This finding aligns with the growing recognition of the potential economic benefits of a circular economy, including cost savings from waste reduction, innovation opportunities, and enhanced brand reputation. It suggests that companies embracing circular economy principles are more likely to achieve better financial performance compared to those neglecting such practices.

The lack of significant influence of managerial ownership on both financial and overall company performance suggests that the level of ownership by managers or executives does not directly translate into improved organizational performance. Other factors, such as leadership style, strategic decision-making, or organizational culture, might have a more prominent role in driving company performance.

Furthermore, the significant influence of production diversity on overall company performance highlights the importance of offering a diverse range of products or goods to achieve better overall performance. This suggests that catering to various market segments or consumer preferences through product diversification can contribute to the overall success of the company.

It is important to note that financial performance was found to significantly impact overall company performance. This emphasizes the critical role of financial success in driving the overall success and performance of companies, which aligns with established theories and practices in the field of business management.

On the other hand, the study findings highlight the significant and positive mediating role of financial performance in the relationship between CE and company performance. The study suggests that enhancing CE can serve as a viable strategy for improving company performance, as it contributes to achieving favorable financial outcomes. Companies demonstrating strong financial performance tend to attract higher investor valuation, and CE-based resources, play a key role in enhancing financial performance. Therefore, financial performance can be considered an intervention variable in the relationship between CE and firm value.

These results emphasize the significance of circular economy practices and the need for strategic decision-making beyond product diversity or managerial ownership in improving financial and overall company performance. Companies should focus on integrating circular economy principles into their operations to reap the potential economic benefits and drive sustainable growth. Further research and exploration of specific mechanisms and strategies within circular economy implementation may provide deeper insights into maximizing financial and overall performance in a circular economy context.

The study reveals that financial performance does not mediate the relationship between managerial ownership and company performance significantly. Consequently,

managerial ownership does not exert a significant influence on decision-making at the General Meeting of Shareholders. Additionally, the limited percentage of managerial ownership restricts the ability of shareholders and financial management to effectively address conflicts of interest through management's ownership of shares.

6. Conclusions

This research paper has undertaken a comprehensive exploration of the intricate interplay between circular economy practices and business performance, facilitated by the construction of an intricate mathematical model and meticulous statistical scrutiny. The outcomes not only underscore the substantial import of embracing circular economy principles in steering enhanced financial performance and broader company prosperity but also beckon for a more nuanced acknowledgment of the research's limitations and avenues for future exploration.

In the realm of limitations, this study acknowledges the non-significant sway of production diversity on financial performance and the lack of a comparable influence of managerial ownership on overall company performance. Notwithstanding, the observed notable impact of circular economy practices on financial performance underscores the promise of adopting these principles, entailing augmented financial outcomes, streamlined costs, fertile grounds for innovation, and a fortified brand image. An overriding inference is the imperative role of financial performance as a harbinger of overall company success, necessitating strategic deliberations extending beyond considerations of product diversity or managerial ownership.

These revelations collectively advocate for a corporate shift towards embedding circular economy principles into operational frameworks to engender sustainable expansion and optimize both financial and holistic performance. However, it is imperative to recognize that the current study is bound by certain limitations that warrant further exploration. Future investigations should delve deeper into dissecting the mechanics and strategies underlying circular economy implementation to concretize these envisioned benefits.

The crafted mathematical model and painstaking statistical analysis not only furnish an enduring scaffold for assessing the circular economy's ramifications but also offer a roadmap guiding businesses, policymakers, and stakeholders in informed decisions for nurturing sustainable growth and realizing enhanced financial and overall company performance. To forge a more incisive comprehension of the predictive potential of the model and the multifaceted impacts of circular economy dynamics, future endeavors can extend their purview to encompass additional variables and factors, thus enriching the holistic tapestry of the circular economy's potential as a catalyst for business triumph.

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Abbreviations

ROE	Return on equity
PD	Production diversity
CE	Circular economy
ICE	Impact of circular economy

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