

# **Eco-Efficiency Dynamics in Financial Holding Companies: Evidence from Taiwan Using a Network DEA–DuPont Framework**

**Cheng-Wen Lee<sup>1</sup> and Sephali Bera<sup>2</sup>**

## **Abstract**

In the era of sustainable finance and digital transformation, financial institutions are increasingly required to balance profitability with environmental responsibility. This study develops an integrated analytical framework to evaluate eco-efficiency by combining a two-stage Dynamic Network Data Envelopment Analysis (DDEA) model with DuPont financial decomposition. Using panel data from Taiwan's financial holding companies over the period 2016–2020, the proposed model captures both intertemporal dynamics and internal production structures, linking economic performance with environmental outcomes. The first stage assesses economic efficiency using financial and human capital inputs to generate interest income, while the second stage evaluates environmental efficiency by incorporating undesirable outputs such as waste and greenhouse gas emissions. Empirical results reveal that improvements in return on equity are primarily driven by profitability and financial leverage rather than asset utilization efficiency. Furthermore, eco-efficiency demonstrates a non-linear but converging trend, while environmental efficiency exhibits increasing divergence across firms. These findings highlight a structural imbalance between financial and environmental performance, reflecting a sustainability paradox within the financial sector. The study contributes to the literature by integrating financial performance drivers with eco-efficiency measurement and offers practical implications for policymakers and managers seeking to promote sustainable financial systems.

**JEL classification numbers:** G21, C67, Q56.

**Keywords:** Eco-Efficiency, Dynamic Network DEA, DuPont Analysis, Financial Holding Companies.

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## 1. Introduction

In the context of the digital era, financial institutions are increasingly leveraging data-driven technologies and digital infrastructures to enhance operational efficiency and sustainability performance. The dynamic efficiency framework adopted in this study provides a robust foundation for evaluating such digitally enabled transformations, even though the empirical analysis primarily focuses on structural and environmental performance indicators. At the same time, escalating environmental pressures have emerged as a pervasive global risk, necessitating immediate and coordinated actions to mitigate ecological degradation. Rapid industrial expansion and sustained economic growth have intensified the overexploitation of natural resources and disrupted ecological balance, thereby challenging the long-term viability of conventional development paradigms. Within this context, eco-efficiency has gained prominence as a critical framework that aligns economic value creation with environmental sustainability by promoting growth while minimizing adverse ecological impacts.

By emphasizing the efficient use of resources to generate value with reduced environmental harm, eco-efficiency reflects the intrinsic interdependence among economic, social, and ecological systems (Fukuyama & Tan, 2023). As environmental constraints continue to tighten, enhancing eco-efficiency becomes essential for achieving sustainable development objectives and long-term resilience. Accordingly, integrating economic growth with environmental protection through improved resource efficiency and reduced ecological footprints has become both a rational and necessary strategy for advancing global sustainability.

The enhancement of firms' environmental practices produces beneficial spillover effects for society, improving resource utilization, mitigating ecological risks, and supporting long-term economic resilience (Krueger et al., 2020; Schlehuber et al., 2025). Prior research indicates that socially responsible and ethical investment strategies do not necessarily lead to inferior financial performance; rather, they can align with or even enhance returns (Broadstock et al., 2021). In particular, evidence from emerging markets suggests that sustainable investment portfolios may outperform conventional ones, especially under conditions of heightened environmental risk, such as air pollution or climate-related disruptions (Bolton & Kacperczyk, 2021; Broadstock et al., 2021). Similarly, recent studies confirm that well-designed investment strategies incorporating environmental considerations can improve portfolio resilience and value, reinforcing the compatibility between ethical behavior and financial performance (Liu et al., 2021).

In response to these sustainability-oriented outcomes, prior research has proposed diverse analytical frameworks to measure eco-efficiency across various contexts, including linear programming techniques, risk-adjusted optimization models, and non-parametric methods such as Data Envelopment Analysis (DEA) (Emrouznejad et al., 2019). Among these, DEA has become one of the most widely adopted and effective methods for evaluating operational and environmental efficiency due to its ability to handle multiple inputs and outputs without requiring predefined

functional forms (Tavana et al., 2022). Extending this approach, recent studies have employed Dynamic Network DEA (DDEA) models to capture intertemporal dependencies and internal production structures, thereby providing a more comprehensive assessment of efficiency dynamics (Tone & Tsutsui, 2014). For instance, applications in the banking sector demonstrate that DDEA effectively captures the evolution of financial and environmental performance over time (Chen et al., 2019).

Achieving higher levels of eco-efficiency calls for the systematic incorporation of sustainability considerations into organizational decision-making processes and regulatory frameworks. Within this context, DEA-based techniques serve as powerful analytical instruments, enabling comprehensive evaluation of sustainability performance while uncovering inefficiencies across firms and sectors (Moutinho et al., 2021; Tavana et al., 2022). Against this backdrop, the present study contributes to the literature by empirically examining the relationship between financial performance and eco-efficiency in Taiwan's Financial Holding Companies (FHCs). Taiwan's financial system has undergone substantial institutional reforms aimed at improving efficiency, competitiveness, and resilience. However, despite these efforts, financial institutions in Taiwan continue to face structural limitations, including relatively small scale, market homogeneity, and limited international competitiveness (Lin et al., 2022).

Although existing research has introduced numerous models for assessing eco-efficiency, a substantial proportion depend on judgment-based weighting methods, potentially undermining the consistency and impartiality of the results (Tavana et al., 2022). To address this limitation, this study adopts a quantitative and integrated approach by combining Dynamic Network DEA with DuPont analysis. Specifically, the DuPont framework decomposes Return on Equity (ROE) into Net Profit Margin (NPM), Asset Turnover Ratio (ATR), and Equity Multiplier (EM), enabling a deeper understanding of the financial mechanisms underlying variations in eco-efficiency (Liu et al., 2020). By integrating DDEA and DuPont analysis, this study provides a multidimensional evaluation of both financial and environmental performance, offering novel insights into how financial institutions balance profitability with sustainability objectives in an evolving economic and regulatory landscape.

## **2. Literature Review**

### **2.1 Selection of Financial Inputs and Outputs in Banking Efficiency Studies**

The specification of input and output variables is a central issue in efficiency analysis, particularly in the banking and financial services sector, where production processes are inherently intangible and multi-dimensional. Unlike manufacturing industries, financial institutions do not transform physical goods but instead perform intermediation functions, including capital allocation, liquidity transformation, and risk management (Fethi & Pasiouras, 2010). Consequently, the selection of variables must reflect both resource utilization and value creation mechanisms within financial systems.

Two dominant paradigms—the production approach and the intermediation approach—have been widely adopted in the literature. The production approach conceptualizes banks as service providers, focusing on operational activities such as account processing and transaction services, where labor and capital serve as inputs, and service outputs are measured by the number of accounts or transactions. However, this approach is often criticized for its limited ability to capture the broader financial role of banks (Paradi et al., 2011).

In contrast, the intermediation approach has gained stronger empirical support, as it reflects the core function of financial institutions in transforming financial resources into earning assets. Under this framework, inputs typically include capital, labor, and financial resources, while outputs are measured by interest income, loans, and revenue generation (Chen et al., 2019; Tavana et al., 2022). Recent studies further argue that balance-sheet-based variables provide a more comprehensive representation of banking performance, particularly in the context of financial holding companies where diversified operations are prevalent (Kumar et al., 2022). Moreover, emerging research highlights that efficiency measurement in financial institutions should not only capture static resource allocation but also account for dynamic adjustments and structural changes driven by regulatory reforms, technological innovation, and ESG integration. This perspective reinforces the importance of selecting variables that are both economically meaningful and temporally comparable. Accordingly, this study adopts total equity and number of employees as input variables, representing financial capital and human resources, respectively, while total interest income is used as the primary output to capture value creation. This selection aligns with prior empirical studies and ensures consistency with the intermediation approach, while also supporting the dynamic evaluation of financial performance across time.

### **2.2 Environmental Inputs and Undesirable Outputs in Eco-Efficiency Measurement**

Traditional efficiency models assume that all outputs are desirable; however, this assumption is inadequate in the context of sustainability, where production processes often generate undesirable outputs such as pollution and waste. The concept of eco-efficiency explicitly incorporates these environmental externalities,

requiring analytical frameworks that can simultaneously maximize desirable outputs while minimizing undesirable ones (Fethi & Pasiouras, 2010). Recent advances in DEA modeling have addressed this limitation by incorporating undesirable outputs into the production possibility set, enabling a more realistic representation of environmental performance (Tavana et al., 2022). In this context, environmental inputs commonly include energy consumption, water usage, and material intensity, while undesirable outputs encompass greenhouse gas emissions, wastewater discharge, and solid waste generation (Halkos & Petrou, 2019).

Although the financial sector is not traditionally classified as a high-pollution industry, its environmental impact is increasingly recognized through both direct operational activities and indirect financing channels. Financial institutions influence environmental outcomes by allocating capital to industries with varying environmental footprints, thereby acting as key enablers of sustainable or unsustainable development (Bolton & Kacperczyk, 2021). Consequently, evaluating eco-efficiency in the financial sector requires consideration of both internal resource consumption and external environmental implications.

Recent studies emphasize that integrating environmental indicators into financial efficiency analysis enhances the explanatory power of models and supports the transition toward sustainable finance, such as environmental economics, data envelopment analysis, etc. (Zhou & Wan, 2024). Furthermore, the inclusion of undesirable outputs allows researchers to identify trade-offs between economic performance and environmental responsibility, which are often overlooked in conventional financial analysis (Tone, 2001). In line with these developments, this study incorporates energy consumption, water usage, waste generation, and greenhouse gas emissions as undesirable outputs, thereby capturing the environmental dimension of performance. This approach enables a more comprehensive assessment of eco-efficiency and aligns with global sustainability reporting standards and ESG frameworks.

### **2.3 Dynamic Network DEA Framework for Multi-Stage Eco-Efficiency Evaluation**

A major limitation of conventional DEA models is their “black-box” nature, which obscures the internal structure of production processes. To overcome this limitation, network DEA models have been developed to explicitly represent multi-stage systems, where intermediate products link different stages of production (Tone & Tsutsui, 2014; Kao, 2014). In recent years, two-stage and multi-stage DEA models have gained prominence in sustainability research, as they allow for the decomposition of efficiency into distinct components, such as economic and environmental performance (Tavana et al., 2022). This approach is particularly relevant for financial institutions, where operational processes involve sequential transformations of inputs into financial outputs and subsequently into broader sustainability outcomes.

Intermediate variables play a critical role in this framework, serving as linking

mechanisms between stages. For example, financial outputs such as revenue or interest income can be treated as intermediate products that influence subsequent environmental performance, reflecting the interconnected nature of economic and ecological systems (Chen et al., 2019). Furthermore, the integration of a dynamic perspective enhances the analytical power of network DEA by capturing intertemporal dependencies and carry-over effects. This is particularly important in sustainability research, where the impacts of resource allocation decisions often unfold over time (Bauer et al., 1998; Tone & Tsutsui, 2014). Dynamic models enable the assessment of not only efficiency levels but also performance stability, trends, and path dependencies.

Accordingly, this study adopts a two-stage Dynamic Network DEA framework, in which the first stage represents economic performance and the second stage captures environmental performance. Financial outputs from the first stage are treated as intermediate linkages, enabling a comprehensive evaluation of how financial activities influence sustainability outcomes over time.

#### **2.4 Theoretical Foundations of Eco-Efficiency in Financial Institutions**

The evaluation of eco-efficiency in financial holding companies requires a theoretical framework that explains the interaction, imbalance, and dynamic evolution between financial performance and environmental sustainability. While prior research has largely emphasized efficiency measurement, limited attention has been paid to the mechanisms underlying the divergence between economic efficiency (FERR) and environmental efficiency (SERR). To address this gap, this study adopts a focused theoretical lens integrating the Resource-Based View (RBV) and Paradox Theory, which directly align with the study's research questions and empirical framework (Shahzad et al., 2020; Bui et al., 2021).

From an RBV perspective, firms achieve superior performance through the effective deployment of internal resources and capabilities. In financial holding companies, eco-efficiency reflects the ability to transform financial and organizational resources into both economic outputs (e.g., profitability) and environmental outcomes (e.g., reduced emissions and resource use). For example, the DuPont decomposition—comprising Net Profit Margin (NPM), Asset Turnover Ratio (ATR), and Equity Multiplier (EM)—captures key dimensions of resource utilization and financial capability. These components serve as strategic drivers of eco-efficiency, influencing how capital is allocated and operational processes are managed. The two-stage DDEA framework further operationalizes this perspective by modeling how resources are distributed across economic and environmental stages, enabling an assessment of whether stronger financial capabilities translate into improved sustainability performance (Tavana et al., 2022; Wang, 2024). However, RBV alone cannot explain the observed imbalance between FERR and SERR. To address this, Paradox Theory is employed to capture the inherent tension between short-term financial performance and long-term environmental sustainability. Investments in sustainability—such as green financing and pollution

control—often involve higher costs and delayed returns, potentially constraining short-term profitability. Conversely, prioritizing financial efficiency may limit the resources available for environmental initiatives.

### **3. Methodology**

#### **3.1 Dynamic Network DEA Framework for Assessing Sustainable Financial Efficiency**

This study employs a two-stage Dynamic Network Data Envelopment Analysis (DDEA) framework to evaluate the eco-efficiency of Taiwan's financial holding companies (FHCs). Compared with conventional static DEA models, the dynamic network DEA approach offers a more robust analytical structure by explicitly incorporating both intertemporal dependencies and internal production processes. This enables a more comprehensive assessment of how decision-making units (DMUs) allocate resources and generate outputs across multiple periods while accounting for carry-over effects and structural linkages (Tone & Tsutsui, 2014; Kao, 2014).

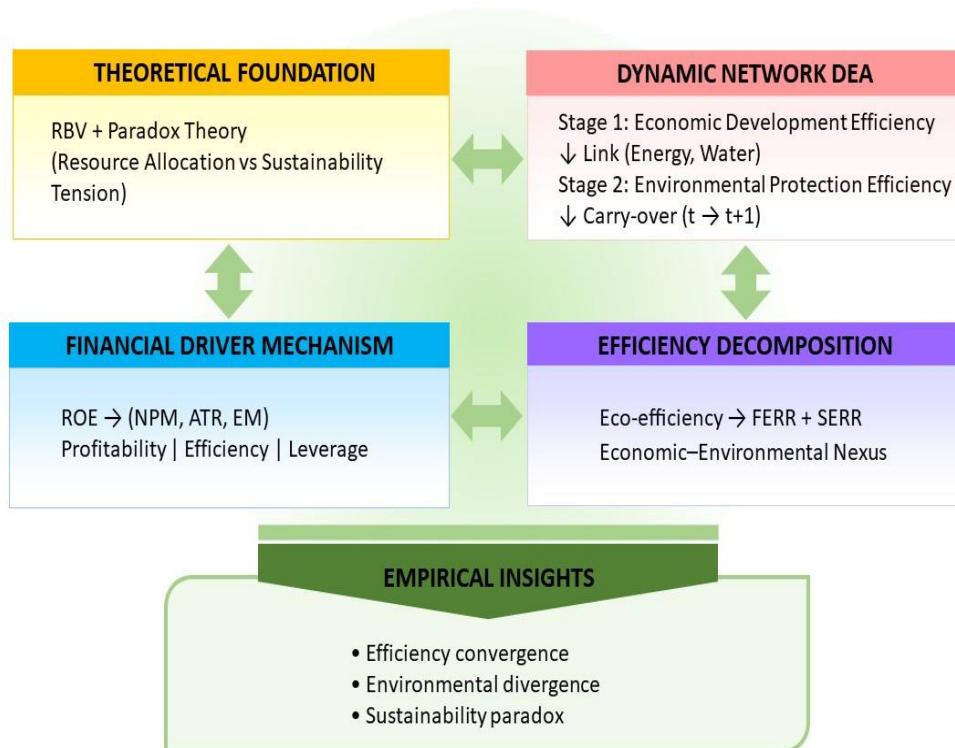
This tension gives rise to a sustainability paradox, in which financial and environmental objectives are pursued simultaneously yet are not always aligned (Hahn et al., 2018; Shevchenko et al., 2022). The empirical findings of this study—particularly the persistent gap between FERR and SERR and the divergence in environmental efficiency—provide evidence of this paradox. Moreover, the dynamic structure of the DDEA model reveals that these tensions evolve, reflecting path dependency and intertemporal trade-offs. Accordingly, eco-efficiency is conceptualized not as a static outcome but as a dynamic, tension-driven process, shaped by the interaction between financial resource allocation and sustainability objectives. This integrated theoretical perspective complements the DDEA–DuPont framework and strengthens the study's contribution by explaining the mechanisms underlying variation in efficiency in the financial sector. Based on the literature review, this study conceptualizes an integrated theoretical–methodological framework, as illustrated in Figure 1.

The adoption of a dynamic network structure addresses two key limitations in traditional efficiency analysis. First, standard DEA models treat firms as “black boxes,” overlooking the internal mechanisms through which inputs are transformed into outputs. Second, static models fail to capture temporal adjustments, thereby limiting the ability to analyze performance evolution and sustainability trajectories. By integrating both network and dynamic features, the DDEA framework allows for the decomposition of efficiency into stage-specific components while simultaneously capturing longitudinal performance dynamics.

Figure 1 presents an integrated theoretical–methodological framework that connects foundational theories, analytical methods, and empirical insights to examine eco-efficiency in financial institutions. At the theoretical level, the framework is grounded in the Resource-Based View (RBV) and paradox theory, which jointly emphasize the inherent tension between resource allocation for economic

performance and the pursuit of environmental sustainability. This tension provides the conceptual basis for analyzing how firms balance profitability and sustainability objectives.

Building on this foundation, the framework employs a dynamic network Data Envelopment Analysis (DEA) approach as the core methodological tool. The model is structured into two interrelated stages. Stage 1 evaluates economic development efficiency, where traditional inputs such as capital and labor generate desirable outputs alongside intermediate products, including energy and water consumption. These intermediate variables serve a dual role, acting as both outputs of the economic stage and inputs to Stage 2. Stage 2 assesses environmental protection efficiency by incorporating undesirable outputs such as waste, wastewater, and greenhouse gas emissions. Importantly, the model captures intertemporal dynamics through carry-over effects, allowing performance in one period ( $t$ ) to influence outcomes in the subsequent period ( $t+1$ ).



**Figure 1: Integrated Theoretical–Methodological Framework**

To further interpret the drivers of performance, the framework integrates a financial mechanism based on the DuPont decomposition of return on equity (ROE). Specifically, ROE is decomposed into net profit margin (NPM), asset turnover ratio (ATR), and equity multiplier (EM), representing profitability, operational efficiency, and financial leverage, respectively. This decomposition enables a

deeper understanding of how financial strategies and operational decisions influence both economic and environmental efficiency outcomes.

In addition, the framework incorporates an efficiency decomposition perspective, where overall eco-efficiency is divided into financial efficiency (FERR) and sustainability-related environmental efficiency (SERR). This decomposition highlights the economic–environmental nexus and allows for a more nuanced assessment of whether improvements in financial performance are aligned with or come at the expense of environmental outcomes.

Finally, the integration of these components leads to key empirical insights. The framework facilitates the identification of efficiency convergence across firms over time, while also revealing divergence in environmental performance. This dual pattern ultimately reflects a sustainability paradox, where firms may achieve improvements in economic efficiency without corresponding gains in environmental efficiency. Overall, Figure 1 illustrates a coherent structure that links theory, methodology, and empirical analysis to provide a comprehensive understanding of eco-efficiency dynamics in the context of sustainable finance.

### **3.2 First Stage: Economic Development Efficiency**

Within each time period, the first stage represents the economic production process of financial holding companies (FHCs), as illustrated in the upper section of the diagram. In this stage, total equity and the number of employees are specified as input variables, capturing the firm’s financial capital and human capital, respectively. These inputs are transformed through the operational and financial intermediation activities of the institution, reflecting its core business functions. The primary desirable output is total interest income, which serves as a proxy for the firm’s ability to generate revenue from its allocated resources. Accordingly, this stage evaluates how efficiently FHCs convert financial and organizational inputs into value-generating outputs, thereby reflecting both operational efficiency and financial performance (Popescu et al., 2024). The use of an oval node labeled “economic development efficiency” highlights that this stage is conceptualized not merely as a production process but as an efficiency evaluation component within the network structure, emphasizing its role in performance measurement rather than solely depicting input–output transformation.

A key feature of the proposed model is the incorporation of intermediate variables (link variables) that connect the first and second stages of the production process. Specifically, energy (power) consumption and water consumption are introduced as linking variables between economic and environmental performance. These variables perform a dual function within the network structure: on the one hand, they represent outputs of the economic stage, reflecting the level of resource utilization generated through financial and operational activities; on the other hand, they serve as inputs to the environmental stage, capturing the environmental burden that must be managed in subsequent processes. The inclusion of these intermediate linkages transforms the analytical framework from a traditional “black box” model

into a network-based system, enabling the explicit representation of internal transmission mechanisms between financial activities and environmental outcomes (Chen et al., 2019; Jiang et al., 2025). This structure more accurately reflects real-world conditions, where economic production processes are inherently associated with resource consumption and environmental pressures, thereby providing a more realistic and policy-relevant assessment of eco-efficiency (Liu et al., 2020; Wang, 2024; Li et al., 2025).

### 3.3 Second Stage: Environmental Protection Efficiency

The second stage evaluates the environmental performance of financial holding companies. In this stage, energy consumption and water consumption, carried over as intermediate link variables from the first stage, are treated as inputs that reflect the level of resource utilization associated with financial operations. The corresponding outputs are specified as undesirable outputs, including waste generation and greenhouse gas emissions, which capture the environmental burdens arising from operational activities. This stage assesses how efficiently financial institutions manage environmental resources and mitigate ecological impacts, thereby providing a comprehensive measure of sustainability performance. The explicit incorporation of undesirable outputs is essential, as it enables the model to align with the eco-efficiency principle of maximizing desirable outputs while minimizing environmental harm, which has been widely emphasized in recent sustainability and efficiency studies (Tavana et al., 2022; Halkos & Petrou, 2019). The oval node labeled “environmental protection efficiency” represents this evaluative function, serving as a complementary component to the economic efficiency assessed in the first stage and ensuring a comprehensive analysis of both financial and environmental dimensions within the network framework.

In addition, the dashed arrows in the figure represent carry-over variables, which connect outputs and intermediate variables from period  $t$  to period  $t+1$ , thereby capturing the intertemporal continuity of the production process. These carry-over components reflect persistent environmental impacts, such as the accumulation of emissions, ongoing resource usage patterns, and structural operational characteristics that extend beyond a single time period. By incorporating these elements, the model accounts for path dependency, whereby past decisions and performance outcomes influence current and future efficiency levels. This feature is particularly important in the context of sustainable finance, as environmental consequences are inherently long-term and cumulative, rather than instantaneous, and therefore require a dynamic analytical framework capable of capturing delayed and persistent effects on sustainability performance (Tone, 2021; Fukuyama, H.; Weber, 2017; Zhang et al., 2023).

### 3.4 Economic–Environmental Nexus

Figure 1 conceptualizes the proposed DDEA framework as an integrated system that simultaneously captures the multidimensional nature of eco-efficiency by linking economic performance with environmental sustainability. Unlike

conventional efficiency models that treat production processes as isolated or static, the present framework explicitly decomposes efficiency into economic and environmental components, while embedding both intra-stage linkages and intertemporal dependencies within a unified analytical structure. This design enables a more nuanced understanding of how financial institutions generate value and manage environmental externalities in a coordinated manner (Tone & Tsutsui, 2014; Kao, 2014; Fukuyama & Weber, 2017).

A key implication of this integrated structure is the recognition of a bidirectional and dynamic nexus between financial performance and environmental outcomes. Specifically, resource allocation decisions made in the economic stage—such as capital deployment and operational intensity—directly shape environmental impacts in the subsequent stage through resource consumption and emissions generation. At the same time, environmental inefficiencies, once generated, may persist across periods due to structural rigidities and cumulative effects, thereby influencing future performance trajectories. This dynamic interaction reflects the concept of path dependency, which has been increasingly emphasized in recent sustainability and financial studies (Li et al., 2025; Zhang et al., 2023).

Moreover, by explicitly modeling intermediate link variables and carry-over effects, the framework captures the complex transmission mechanisms through which financial activities translate into sustainability outcomes. This approach aligns with the growing body of literature on sustainable finance, which highlights that environmental impacts are often indirect, delayed, and embedded within financial decision-making processes (Bolton & Kacperczyk, 2021). Consequently, eco-efficiency should not be interpreted as a static or one-period measure, but rather as a dynamic and evolving construct, shaped by the continuous interaction between operational performance, resource utilization, and environmental management over time. Overall, the proposed framework advances the measurement of eco-efficiency by providing a structurally explicit and temporally sensitive evaluation tool, offering more realistic and policy-relevant insights into how financial institutions balance profitability with environmental responsibility under increasingly stringent ESG and regulatory pressures.

## **4. Case Study**

### **4.1 DuPont-Based Analytical Framework**

The DuPont analysis provides a systematic and widely adopted framework for decomposing corporate financial performance into its fundamental drivers. As noted in recent studies (Timothy, 2022), this approach enables a more transparent evaluation of how firms generate returns by disentangling the underlying components of profitability, operational efficiency, and financial structure. In this study, Return on Equity (ROE), as defined in Eq. (1), is employed as the primary indicator of financial performance, capturing the effectiveness with which financial holding companies (FHCs) utilize shareholders' equity to generate returns. ROE has been extensively recognized as a critical metric for assessing managerial

efficiency and guiding strategic financial decisions (Dreżewski et al., 2018; Nissim, 2022).

$$ROE = NPM \times ATR \times EM \quad (1)$$

**Table 1: The Definitions and Corresponding Formulations of Variables**

Component	Mathematical Definition	Formula	Economic Interpretation	Role in This Study
Return on Equity (ROE)	Overall profitability of shareholders' investment	$ROE = \frac{\text{Net Income}}{\text{Equity}}$	Measures the firm's ability to generate returns for shareholders using its equity base	Serves as the primary financial performance indicator, linked to eco-efficiency outcomes
Net Profit Margin (NPM)	Profitability per unit of revenue	$NPM = \frac{\text{Net Income}}{\text{Revenue}}$	Reflects operational efficiency, indicating how effectively revenue is converted into profit	Captures cost control and operational performance, influencing eco-efficiency through resource utilization
Asset Turnover Ratio (ATR)	Revenue generated per unit of assets	$ATR = \frac{\text{Revenue}}{\text{Total Assets}}$	Measures asset utilization efficiency, reflecting how effectively assets are used to generate income	Represents resource allocation efficiency, linking financial operations to environmental resource use
Equity Multiplier (EM)	Financial leverage ratio	$EM = \frac{\text{Total Assets}}{\text{Equity}}$	Indicates the degree of financial leverage, showing reliance on debt financing	Captures capital structure decisions, which may affect long-term sustainability and risk exposure
DuPont Identity	Multiplicative decomposition of ROE	$ROE = NPM \times ATR \times EM$	Decomposes financial performance into profitability, efficiency, and leverage components	Provides the analytical bridge between financial performance and eco-efficiency in the DDEA model

Following the classical DuPont decomposition, ROE is expressed as the product of three interrelated components: Net Profit Margin (NPM), Asset Turnover Ratio (ATR), and Equity Multiplier (EM). These components capture distinct yet complementary dimensions of financial performance. Specifically, NPM reflects operational profitability, indicating the firm's ability to convert revenues into net income; ATR measures asset utilization efficiency, representing how effectively the firm employs its asset base to generate revenue; and EM captures financial leverage, illustrating the extent to which a firm relies on debt financing relative to equity. The definitions and corresponding formulations of these variables are summarized in Table 1.

The integration of DuPont analysis into this study serves a critical diagnostic function by identifying the primary drivers of variations in ROE across firms and over time. This decomposition allows for a more nuanced interpretation of financial performance, distinguishing whether changes in profitability are driven by operational efficiency, asset management, or leverage decisions. Such insights are particularly relevant in the financial sector, where strategic trade-offs between risk, return, and capital structure play a central role in determining firm value and long-term sustainability (Kumar et al., 2022).

Furthermore, in this study, the DuPont framework complements the DDEA model by linking financial performance drivers to eco-efficiency outcomes. By decomposing ROE into its constituent components, the analysis bridges internal financial mechanisms and external sustainability performance, offering a more comprehensive understanding of how financial strategies influence eco-efficiency within Taiwan's financial holding companies. To examine the interrelationships among the components of the DuPont framework, this study employs Spearman's rank correlation analysis, which is appropriate given the non-normal distribution of the variables. The results are presented in Table 2.

**Table 2: Spearman Rank Correlation of DuPont Components**

Variables	ROE	NPM	ATR	EM
ROE	1			
NPM	0.356** (0.005)	1		
ATR	0.165 (0.208)	-0.558** (0.000)	1	
EM	0.169 (0.197)	-0.600** (0.000)	0.202 (0.122)	1

Note: Significant at the 0.01 level (2-tailed)

First, ROE exhibits a moderate and statistically significant positive correlation with Net Profit Margin (NPM) ( $\rho = 0.356$ ,  $p = 0.005$ ), indicating that profitability plays a dominant role in driving shareholder returns. This finding suggests that firms with stronger cost control and higher profit generation capacity tend to achieve superior financial performance.

In contrast, the relationships between ROE and both Asset Turnover Ratio (ATR) ( $\rho = 0.165$ ,  $p = 0.208$ ) and Equity Multiplier (EM) ( $\rho = 0.169$ ,  $p = 0.197$ ) are positive but statistically insignificant. This implies that, within the sample of Taiwanese financial holding companies, asset utilization efficiency and financial leverage do not exert a strong direct influence on ROE, highlighting the relatively greater importance of profitability over scale efficiency or leverage effects.

A notable finding is the significant negative correlation between NPM and ATR ( $\rho = -0.558$ ,  $p < 0.01$ ), as well as between NPM and EM ( $\rho = -0.600$ ,  $p < 0.01$ ). These results suggest the presence of a trade-off relationship within the DuPont components. Specifically, firms achieving higher profit margins may do so at the expense of asset utilization efficiency or by adopting more conservative leverage strategies. This reflects differing strategic orientations among financial institutions, where some prioritize profitability, while others focus on asset expansion or leverage optimization.

Furthermore, the weak and insignificant correlation between ATR and EM ( $\rho = 0.202$ ,  $p = 0.122$ ) indicates that asset utilization and financial leverage operate relatively independently within the sample. This independence suggests that financial institutions may adopt heterogeneous strategies in balancing operational efficiency and capital structure. Overall, the correlation analysis reveals that profitability (NPM) is the primary driver of ROE, while the interactions among DuPont components exhibit structural trade-offs rather than complementary effects. These findings provide important empirical support for the subsequent analysis, particularly in linking financial performance drivers to eco-efficiency outcomes within the DDEA framework. In particular, the observed trade-offs imply that improvements in financial performance may not uniformly translate into sustainability gains, thereby reinforcing the need for a multi-dimensional efficiency evaluation approach.

Table 3 reports the results of the DuPont analysis for Taiwan's financial holding companies (FHCs) over the period 2016–2020. Overall, the findings reveal that Return on Equity (ROE) exhibits a non-linear yet upward trend prior to 2020, followed by a noticeable decline in the final year of the sample. Specifically, ROE increased from 3.58% in 2016 to a peak of 6.63% in 2019, before decreasing to 4.57% in 2020. This pattern suggests that financial performance improved steadily during the pre-2020 period, but deteriorated thereafter, likely reflecting the adverse impact of exogenous shocks—most notably the COVID-19 pandemic—on market conditions, credit risk, and earnings stability.

**Table 3: DuPont Analysis for Taiwan's Financial Holding Companies (2016–2020)**

Metric	2016	2017	2018	2019	2020	Trend Interpretation
ROE (%)	3.5829	4.9616	5.7320	6.6294	4.5688	↑ Growth (2016–2019), ↓ Shock (2020)
NPM (%)	5.8840	11.9422	10.0977	17.6148	13.5649	Strong ↑, volatile, peak in 2019
ATR	0.0128	0.0115	0.0163	0.0162	0.0119	Low, weak efficiency, unstable
EM	5.3394	9.5999	10.2390	10.2113	10.3258	Strong ↑ leverage, stabilizes high
ROE Growth (%)		38.48%	15.53 %	15.66 %	-31.08%	Growth then sharp contraction
NPM Growth (%)		102.96%	-15.45 %	74.44%	-22.99 %	High volatility
ATR Growth (%)		-10.09%	41.89 %	-0.74 %	-26.48 %	Structural inefficiency
EM Growth (%)		79.79 %	6.66 %	-0.27 %	1.12 %	Rapid leverage expansion

A closer examination of the DuPont components provides further insights into the underlying drivers of this trend. The Net Profit Margin (NPM) displays a substantial and sustained upward trajectory, rising sharply from 5.88% in 2016 to 11.94% in 2017, and continuing to increase to a peak of 17.61% in 2019. Although NPM declined to 13.56% in 2020, it remained at a relatively elevated level compared to earlier years. This pattern indicates that FHCs achieved significant improvements in cost efficiency and revenue generation, suggesting enhanced operational profitability and effective expense management, even in the face of external uncertainties.

In contrast, the Asset Turnover Ratio (ATR), which captures the efficiency of asset utilization, exhibits consistently low values with only marginal fluctuations, ranging from 0.0115 to 0.0163 throughout the study period. While slight improvements are observed during 2018–2019, the subsequent decline in 2020 indicates limited progress in enhancing operational efficiency. These persistently low ATR levels suggest that FHCs face structural constraints in converting assets into revenue, which may hinder long-term performance improvement and reduce the effectiveness of resource allocation.

Meanwhile, the Equity Multiplier (EM) shows a pronounced upward trend, increasing from 5.34 in 2016 to above 10.2 from 2018 onward. This indicates a growing reliance on financial leverage to amplify shareholder returns. Although higher leverage contributes positively to ROE, this strategy also implies increased exposure to financial risk, particularly under volatile economic conditions. The elevated EM values observed in later years suggest that FHCs may be increasingly

dependent on debt financing, raising concerns about financial sustainability and risk resilience.

Taken together, the DuPont decomposition indicates that the improvement in ROE prior to 2019 was primarily driven by enhanced profitability (NPM) and increased financial leverage (EM), rather than improvements in asset utilization efficiency (ATR). This imbalance highlights a structural reliance on profitability and leverage-based strategies, rather than operational efficiency gains. The decline in ROE in 2020 further underscores the vulnerability of such a growth model to external shocks, emphasizing the need for a more balanced approach that integrates efficient asset utilization, prudent leverage management, and resilience to macroeconomic uncertainty. From a broader perspective, these findings provide important implications for the subsequent eco-efficiency analysis, as they suggest that financial performance improvements may not necessarily be aligned with sustainable and resource-efficient operational practices. Figure 2 displays the temporal trends in DuPont components from 2016 to 2020.

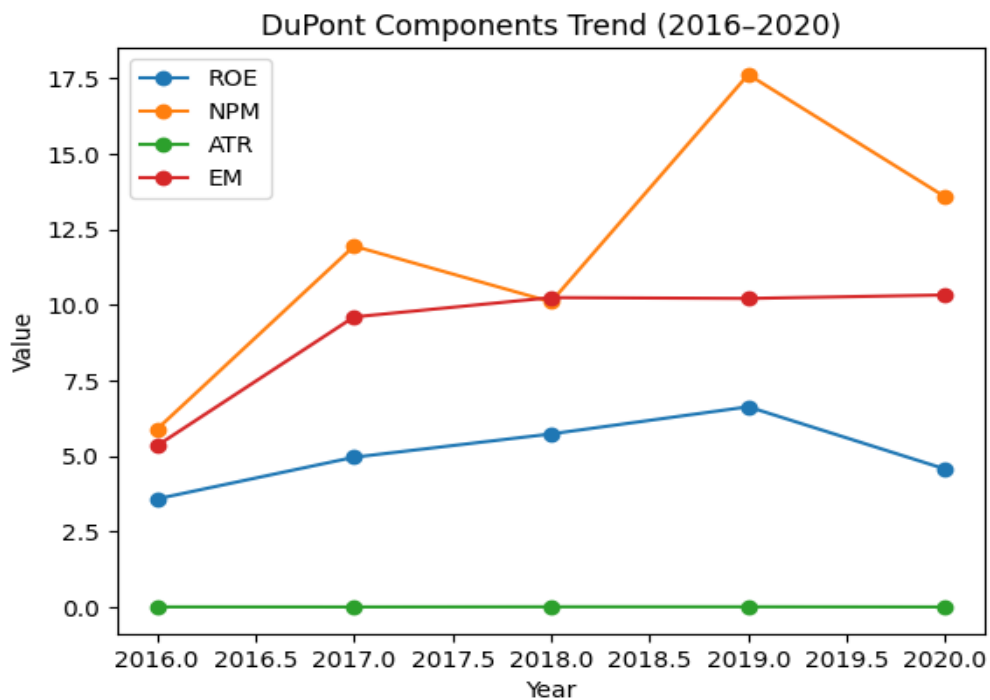


Figure 2: Temporal Trends in DuPont Components (2016–2020)

## **5. Conclusion**

### **5.1 Discussion**

This study provides a comprehensive evaluation of eco-efficiency in Taiwan's financial holding sector by integrating a two-stage Dynamic Network Data Envelopment Analysis (DDEA) framework with DuPont financial decomposition. The findings reveal several important patterns regarding the interaction between financial performance and environmental sustainability.

First, the results indicate that improvements in Return on Equity (ROE) during the study period were primarily driven by profitability (NPM) and financial leverage (EM), rather than enhancements in asset utilization efficiency (ATR). This suggests a structural reliance on margin expansion and leverage strategies, which may raise concerns regarding long-term sustainability and financial resilience.

Second, the eco-efficiency analysis demonstrates a moderate but non-linear improvement trend, with noticeable fluctuations across years. The dynamic DDEA framework reveals that eco-efficiency is not static but evolves over time, reflecting adjustments in both financial operations and environmental management practices.

Third, the decomposition into financial efficiency (FERR) and environmental efficiency (SERR) uncovers a persistent structural imbalance. While environmental efficiency generally exceeds financial efficiency, dispersion analysis indicates that environmental performance remains more heterogeneous across firms. Specifically, eco-efficiency shows a convergence trend, financial efficiency remains relatively stable and homogeneous, and environmental efficiency exhibits emerging divergence in recent years. These findings highlight that sustainability practices are unevenly implemented across institutions and remain in a transitional phase. Overall, the results confirm that eco-efficiency is inherently multi-dimensional and dynamic, requiring analytical approaches that capture both structural relationships and intertemporal evolution.

### **5.2 Implications**

This study contributes to the literature in three key aspects. First, it extends DEA methodology by incorporating a dynamic network structure with undesirable outputs, enabling a more realistic representation of eco-efficiency across multiple periods. Second, it integrates DuPont analysis with eco-efficiency evaluation, establishing a novel linkage between financial performance drivers and sustainability outcomes. Third, by incorporating dispersion and convergence analysis, the study advances understanding of efficiency distribution dynamics, moving beyond traditional average-based assessments.

From a managerial perspective, the findings suggest that financial holding companies should move beyond compliance-driven approaches and adopt strategically embedded sustainability practices. Enhancing environmental risk management—particularly through ESG-based credit evaluation, climate risk integration, and sustainable portfolio allocation—will be essential. As financial institutions increasingly invest in resource-intensive industries, they must address

indirect environmental risks, including water consumption, waste generation, and emissions. Implementing real-time monitoring systems and data-driven environmental management frameworks can improve decision-making and enhance eco-efficiency performance.

From a policy standpoint, regulators should promote the integration of financial and environmental objectives by strengthening ESG disclosure requirements, encouraging green finance initiatives, and supporting sustainable investment frameworks. In the context of Taiwan, particular attention should be given to water resource management, carbon reduction, and pollution control, especially in high-impact industries such as semiconductor manufacturing.

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