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# Efficiency and productivity in the Taiwanese banking industry: A comparative analysis of the pre- and post-bank 3.0 eras

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## ABSTRACT

This study examines the efficiency and productivity of Taiwanese banks during the pre- and post-the third-generation banking transformation (Bank 3.0) periods. It focuses on assessing performance disparities before and after digital transformation initiatives. To achieve this, we utilize Data Envelopment Analysis and the Malmquist Productivity Index to evaluate banks' operational efficiency and dynamic productivity changes. The analysis includes a comparative perspective between financial holding and non-holding banks. By integrating intellectual capital indicators and a comprehensive panel dataset covering the period from 2007 to 2022, the study provides a multifaceted evaluation of the banking industry's performance. The findings reveal that while digital finance initiatives have contributed to overall productivity gains, their effects are uneven. Larger financial holding banks benefit more significantly from technological adoption due to resource advantages and scale economies, whereas smaller banks face greater challenges in adapting to digital transitions. These results underscore structural asymmetries within the sector and highlight the importance of strategic digital planning and adaptive capacity. Importantly, the findings hold practical implications for banking strategy, regulatory design, and financial technology investment in emerging markets, emphasizing the need for supportive policies enabling smaller institutions to transition effectively, ensuring inclusive digital financial development and long-term competitiveness.

**Contribution/ Originality:** This study is among the few that examine the impact of digital financial transformation on bank efficiency and productivity within a newly industrialized economy. By leveraging Taiwan's experience, the findings provide valuable insights and practical implications that can inform banking strategies and policy frameworks in other developing countries facing similar transitions.

## 1. INTRODUCTION

In this era of digital emergence, financial technology (Fintech) is transforming not only the fields of finance and technology but also the broader economic and societal landscape. The development of innovative service models has become an irreversible trend. Although Fintech is widely recognized as a disruptive force, a unified strategy on how institutions should respond remains elusive. The financial industry is experiencing profound structural changes as emerging technologies such as Artificial Intelligence (AI), machine learning, the Internet of Things (IoT), and blockchain reshape various banking functions and service paradigms. Maintaining competitiveness during this transition from legacy systems to agile operational models remains a key challenge.

As Lee (2018), Shen (2017), Lin (2018), Liang (2020), Liao (2019), and Chung (2017) have noted, financial institutions will not vanish due to the rise of Fintech, but will instead evolve their business models while continuing to provide financial services. Technologies perceived as threats can be integrated into existing service offerings, whereas those lacking disruptive potential tend to have limited influence. The core objective of Fintech is to produce cost-efficient financial services that stimulate consumer engagement and generate revenues. Enterprises must map the evolving competitive terrain, identify strategic opportunities, and leverage their organizational capabilities to meet dynamic market demands.

Hung and Luo (2016) argue that Taiwan trails behind many countries in both Fintech innovation and regulation. The government's focus on supporting researchers rather than disruptive innovators has delayed industrial progress. Historically, Bank 1.0 (1472–1980) represented traditional, branch-based banking, requiring customers to be physically present. Bank 2.0 (1981–2007) brought systematization and digitization through ATMs and internet banking.

The third-generation banking transformation (Bank 3.0) (2008–2017), as described by Brett King, marked a shift toward customer-centric digital models. Consumers now rely on digital channels and social networks to choose financial services aligned with their needs. The emergence of Bank 4.0, beginning in 2018, continues this evolution with a focus on seamless, contextual banking experiences.

Xu (2017) posits that Fintech redefines the banking value proposition by emphasizing service over physical presence. Embracing advanced technology is now essential for delivering integrated financial experiences and appealing to younger digital-native customers. Chen (2016) notes that competitive advantage in the digital age stems from customer insight, brand strength, and real-time service delivery powered by predictive algorithms. Fintech startups are not constrained by legacy systems and instead focus on scalable mobile solutions that reach underserved populations, offering an alternative to traditional banking models.

Philippon (2016) and Hu, Ding, Li, Chen, and Yang (2019) criticize the inefficiencies in capital allocation within the financial sector, despite technological advancement. They emphasize that financial innovation has yet to yield substantial consumer benefits, as costs remain high. User innovation, brand image, and government policy positively influence Fintech adoption through perceived trust, ultimately shaping service usage decisions.

Most prior literature has focused primarily on Fintech adoption, with limited attention to comparing pre- and post-the third-generation banking transformation (Bank 3.0) periods. In addition, few studies employ longitudinal datasets or incorporate intellectual capital variables.

To fill this gap, this study uses quarterly panel data from Q1 2005 to Q3 2020 to examine the operational efficiency of Taiwanese banks. DEA is applied to evaluate efficiency, while MPI captures productivity changes across periods. Intellectual capital indicators are incorporated to provide deeper insights. The results aim to support decision-making for regulators, financial institutions, and investors and contribute to the broader academic discourse on digital transformation in emerging markets.

## 2. LITERATURE REVIEW

### *2.1. The Four Stages of Fintech Evolution*

According to the International Monetary Fund (IMF) (2017), financial services have long been influenced by technological advancements, from the exchange of notes in the 12th century to the modern developments of Automated Teller Machines (ATMs), electronic transactions, internet banking, mobile banking, peer-to-peer (P2P) transactions, and blockchain technology. Since the year 2000, the pace of Fintech innovation has accelerated, with innovations that once took a century to materialize now potentially emerging in less than a decade. Based on the research by Arner, Barberis, and Buckley (2016), the evolution of Fintech can be broadly divided into four stages, from Bank 1.0 to Bank 4.0, as shown in Table 1.

**Table 1.** The evolution of fintech.

| Period | Major Events |
|---|---|
| Bank 1.0 (1472-1980) | ■ In 1866, the laying of the transatlantic submarine cable facilitated the internationalization of financial operations. |
| | ■ The 1967 introduction of computers and ATMs marked a significant technological advancement. In the early 1970s, the Federal Reserve's Fedwire electronic funds transfer and clearing network began adopting electronic operations. |
| | ■ From the early 1980s, the financial industry gradually moved toward computerization. |
| Bank 2.0 (1981-2007) | ■ In 1987, the commercial internet service company UUNET was established, spurring the rise of the internet. In 1995, the first purely online bank was founded in the United States. |
| | ■ Most banks began offering financial services through both virtual (online banking) and physical (branch) channels simultaneously. |
| Bank 3.0 (2008-2017) | ■ Advanced technologies such as mobile applications (Apps), artificial intelligence, blockchain, cloud computing, big data, and robotic process automation (RPA) have increasingly been applied in financial services. |
| | ■ Fintech companies and large technology firms have started providing financial services, forming a competitive yet collaborative relationship with traditional financial institutions. |
| | ■ Innovations in business models have led to the mobilization and platformization of financial services. |
| Bank 4.0 (2018-) | ■ Machine learning and deep learning are utilized to analyze big data across all branches, integrate customer needs, and provide the most appropriate real-time recommendations and services for each individual scenario. |
| | ■ In the future, core banking systems including deposits, loans, transfers, cards, checks, bonds, and securities will become more modernized, easier to deploy, and characterized by open features. |

### *2.2. Review of the Impact of Fintech on Banking Operations*

Li (2018) examines how "Fintech" has transformed the banking industry's current operational landscape by observing three key areas: interest income, fee income, and consumer experience. The study suggests future development directions for the banking industry, including the alignment of the financial system with the Fintech ecosystem, investment in innovative payment methods, and the expansion of internet finance. The conclusion emphasizes that Fintech should be approached from the consumer's perspective, with a focus on enhancing the consumer experience.

Shen (2017) explores the trends in Fintech development and the resulting shifts in competitiveness for traditional financial institutions. The study discusses the evolution and future trends of traditional banking in response to Fintech advancements, the creation of new development platforms under the Fintech wave, and the challenges posed by the rapid growth of financial technology. The study further delves into how Fintech innovations can generate low-cost financial services to attract consumers and generate revenue, as well as an in-depth analysis of the global evolution of Fintech innovations and their implications for past and future markets, ultimately accelerating the growth of financial technology.

Lin (2018) investigates the Fintech ecosystem by applying concepts from arena theory and structural hole theory to explain how incumbents and new entrants create opportunities to gain competitive advantages. The study utilizes the resource, process, and value framework to illustrate how organizational capabilities drive decision-making and build competitive advantage. Through the ten propositions presented and a case study on retail banking, the research identifies strategies for banks to address competitive challenges posed by Fintech and provides strategic references for incumbent banks.

Xu (2016) discusses the rise of Fintech startups post-2008 financial crisis, which, through disruptive innovation and advanced technologies, have revolutionized artificial intelligence, mobile payments, big data analytics, and blockchain applications, reshaping the financial industry. This study conducts a literature review and a case analysis of the current state of domestic banks, using Changhua Bank as an example, to explore the opportunities and threats Fintech brings to the Taiwanese banking industry and to suggest potential strategies for the industry.

Chen (2016) primarily explores the evolution of banking services and the development process of Fintech, analyzing Fintech innovations in response to changes in the financial environment. The study examines how banks have developed various electronic channels and financial products to compete in the Fintech market under the evolving financial environment and cost considerations. By analyzing the practical application of Fintech in domestic and international banking, the research also explores potential future developments in Fintech for the Taiwanese banking industry. The study concludes that banking is no longer a "location" but rather a "behavior," and Taiwanese banks must adopt "Double T" strategies "Transboundary" and "Transformation" to face the digital era.

Liang (2020) uses a qualitative research approach to study a case bank recognized for its digital financial wealth management in Taiwan. Through interviews with senior managers of the case bank, the research analyzes the impact of financial digitization on wealth management business and the potential opportunities and challenges in the face of the digital financial wave. The study concludes that "seamless financial services through virtual-real integration," "the digitalization of financial life," "leveraging high-net-worth wealth management opportunities," "enhancing financial literacy for inclusive finance," and "establishing a robust ecosystem for the era of pure internet banks" will be the future development trends for digital financial wealth management in Taiwan.

Liao (2019) aims to understand the benefits of integrating finance and technology and the efforts of various countries in Fintech. Since the World Economic Forum's (WEF) "Future of Financial Services" report in 2015, Fintech has become synonymous with innovation in the financial services industry. The report identifies six innovative insights, including how Fintech's disruptive innovation in traditional finance will gradually change consumer behavior, business models, and industry structures; the most profound mid- to long-term impact will be on the insurance industry; healthy development will rely on the cooperation of governments, the financial industry, and Fintech startups; and that the financial industry will adopt a parallel strategy of competition and cooperation with Fintech startups.

Zhong (2017) highlights how the banking industry is preparing for the arrival of the third-generation banking transformation (Bank 3.0) by formulating human resource transformation plans, establishing digital finance departments, and conducting big data analysis. The industry is also focusing on Fintech and digital application research and development to create new banking models. This study divides all potential influencing factors into six dimensions: service positioning, human resource strategy, service types, marketing strategies, organizational operations, and financial product design, followed by questionnaire design and statistical analysis to understand how Taiwan's banking industry should adjust its business strategies in the face of the Bank 3.0 trend.

Hung and Luo (2016) aim to identify strategies in the search for Fintech investment opportunities. "Fintech" is the convergence of "finance" and "technology," leading to innovative financial services that shift from internal methods to reliance on external providers for online and mobile services. Disruptive innovation can launch new businesses and create new job opportunities.

Philippon (2016) evaluates the potential impact of Fintech on the financial industry, focusing on financial stability and the successful delivery of services. The study emphasizes that the high cost of financial services has led to the emergence of new entrants. Achieving structural changes under current regulations requires significant political, economic, and coordination costs. Although Fintech can bring about deeper changes, regulation faces significant challenges.

Hu et al. (2019) explore the underlying mechanisms behind Fintech services and their expansion strategies are examined, proposing an improved Technology Acceptance Model (TAM) that incorporates factors such as user innovation capability, government support, brand image, and perceived risk into the determinants of trust. The study investigates how users adopt Fintech services and employs structural equation modeling (SEM) to analyze data and test hypotheses, including the relationships among all latent variables. The results confirm that users' trust in Fintech services significantly influences their adoption attitudes.

In the rapidly evolving FinTech landscape, traditional banking institutions are increasingly compelled to transcend legacy business models and embrace innovative strategies and delivery channels to sustain their competitiveness. The extant literature underscores that, in order to avoid disintermediation by agile FinTech entrants, incumbent banks must proactively adapt their operational structures and invest in continuous innovation. As banking progressively shifts from a location-bound service paradigm to a behavior-centric model, institutional frameworks and service mechanisms must undergo corresponding transformation. This transition accentuates the strategic significance of digital competencies, customer-centric design, and real-time responsiveness in preserving institutional relevance. Consequently, existing research indicates that digital transformation not only enhances consumer interaction but also redefines the strategic imperatives and operational configurations of financial institutions. Building upon this foundation, the present study investigates how the transition from traditional banking to the third-generation banking transformation (Bank 3.0) era influences performance outcomes within the Taiwanese banking sector.

Beyond these conceptual insights, rigorous assessment of banking performance in the digital era necessitates robust empirical methodologies. Data Envelopment Analysis (DEA), originally formulated by Charnes, Cooper, and Rhodes (1978) and later refined by Banker, Charnes, and Cooper (1984), has emerged as a foundational non-parametric technique for evaluating the relative efficiency of decision-making units, particularly within financial institutions. Complementing the DEA, the Malmquist Productivity Index (MPI), developed by Färe, Grosskopf, Norris, and Zhang (1994), facilitates the dynamic assessment of productivity changes over time. In comparison to parametric approaches such as Stochastic Frontier Analysis (SFA), DEA is advantageous for its minimal assumptions regarding functional form, though it remains sensitive to outliers and data noise. While applications of DEA and MPI in FinTech-related banking studies remain emergent, growing empirical evidence affirms their efficacy in capturing the operational impacts of digital innovation. Accordingly, this study adopts these analytical tools to assess the effects of digital transformation particularly within the context of the third-generation banking transformation (Bank 3.0) on the efficiency and productivity of Taiwanese banking institutions.

## 3. METHODOLOGY

This section discusses the research methodology in three parts. The first part covers the selection of research samples and data sources. The second part defines the research variables. The third part introduces the research methods employed in this study.

### *3.1. Sample Selection and Sources*

The sample selection for this study is based on the banks listed in the Taiwan Economic Journal (TEJ) database. The selected sample banks include First Commercial Bank, Taichung Commercial Bank, The Shanghai Commercial & Savings Bank, Land Bank of Taiwan, and CTBC Bank, among others, totaling 34 banks. The study period spans from the first quarter of 2005 to the third quarter of 2020, covering a total of 63 quarters. Due to data collection limitations, the study is divided into the pre-third-generation banking transformation (Bank 3.0) and the post-third-generation banking transformation (Bank 3.0) periods, with the pre-Bank 3.0 period running from the first quarter of 2005 to the fourth quarter of 2010, encompassing 25 quarters, and the post-Bank 3.0 period starting from the first quarter of 2011 to the third quarter of 2020, covering 38 quarters.

While the study period spans several significant external shocks, including the 2008 global financial crisis and the onset of the COVID-19 pandemic in 2020, these events are inherently embedded in the quarterly panel data, allowing for an empirical evaluation of their impact within the efficiency and productivity dynamics of Taiwanese banks. Specifically, the inclusion of 63 quarters provides sufficient temporal depth to observe potential deviations in performance during and after such exogenous shocks. Moreover, the application of DEA and Malmquist Productivity Index (MPI) inherently accommodates variations in input–output efficiency over time, enabling the model to reflect both gradual transformations and abrupt disruptions in banking operations. Although these shocks were not modeled as explicit dummy variables, their effects are reflected in the temporal variation and are absorbed into the frontier shift and catch-up components of the MPI framework. This approach ensures that the structural dynamics and real-world disturbances are endogenously captured in the study's analytical design.

To address DEA's sensitivity to outliers and skewed data, this study applied a two-step approach: first, extreme values were winsorized at the 1st and 99th percentiles to minimize the influence of data anomalies; second, descriptive statistics and boxplot diagnostics were used to identify and treat skewness or kurtosis in variable distributions. This ensures the robustness of DEA efficiency estimates and mitigates distortions caused by irregular data.

### *3.2. Definition of Variables*

In this study, the selected input variables not only consider traditional financial indicators but also take into account the competitive advantages that a company might possess in the knowledge economy era. Therefore, intellectual capital variables have been included to compare the operational efficiency of the banking industry before and after the implementation of the third-generation banking transformation (Bank 3.0). The input and output variables are based on relevant literature, including works by Li (2016) and Huang (2018).

To enhance variable validity, all input and output variables were selected based on established empirical literature and industry relevance, particularly referencing Li (2016) and Huang (2018). Construct validity was further reinforced by cross-checking the definitions and data availability from the TEJ database to ensure consistency and reliability. Additionally, robustness checks were conducted through sensitivity analyses, where alternative model specifications were tested, including the exclusion of certain inputs (e.g., operating expenses) and recalculation of efficiency scores. The results remained generally stable, indicating that our DEA and MPI outcomes are not overly dependent on specific variable combinations. As for external factors, although global shocks like the 2008 financial crisis and COVID-19 pandemic were not explicitly modeled as dummy variables, their impact is endogenously captured through the Malmquist Productivity Index's decomposition of frontier shifts and catch-up effects. This allows the model to reflect both abrupt and structural environmental changes over time.

#### *3.2.1. Output Variables*

A. Net Revenue

This variable represents the sum of net interest income and other net non-interest income or loss.

B. Intellectual Capital Variable 1 / Average Output per Employee

This is calculated as revenue divided by the number of employees, indicating the revenue generated by each employee per year. A higher average output per employee reflects greater efficiency in human resource utilization.

C. Interest Income

This includes interest income from loans and discounts, interest income from interbank deposits and borrowings, interest income from bonds, and other interest income.

#### *3.2.2. Input Variables*

A. Intellectual Capital Variable 2 / Organizational Age (Years in Operation)

The longer a company has been established, the more experience, knowledge, and technology it is expected to accumulate, enhancing its development capabilities.

B. Total Assets

This refers to the resources controlled by a company, representing the assets owned or possessed by the enterprise that can be used to operate and settle debts. It is a key indicator of the company's scale and sustainability.

C. Total Equity

This represents the residual interest in the company's resources after deducting liabilities, essentially the portion of assets exceeding liabilities.

D. Number of Employees

This is the total number of employees within the company, reflecting its scale. Employees are considered the most critical resource, encompassing management, R&D, sales, and manufacturing personnel.

E. Operating Expenses

These are the costs incurred within the current period related to the sale of goods, provision of services, or management activities. Operating expenses are a key control item for the company and include selling expenses, administrative expenses, and R&D expenses.

### *3.3. Description of Research Methods*

#### *3.3.1. Data Envelopment Analysis, DEA*

DEA is an efficiency frontier production function method that measures efficiency by enveloping observed data along a frontier. Utilizing mathematical programming techniques, DEA evaluates efficiency using ex-post data without the need for predefined weights. It can handle multiple input and output variables, providing insights into the contribution of each input and output variable to the relative efficiency score. This method not only addresses the limitations of traditional efficiency measurement approaches but also extends the role of mathematical programming from its traditional planning function to a tool for control and evaluation, making it an effective diagnostic tool for organizations (Banker et al., 1984). DEA offers both fairness and objectivity in efficiency measurement.

The earliest studies on efficiency measurement and the frontier of multi-input production factors trace back to Farrell. In his seminal paper, "The Measurement of Productive Efficiency," (Farrell, 1957) three fundamental assumptions underlie his method: (1) the production frontier is composed of the most efficient units, with less efficient units lying within this frontier; (2) the assumption of constant returns to scale (CRS); and (3) the production frontier is convex towards the origin, with no positive slopes at any point.

The DEA model primarily employs envelopment techniques as a substitute for the production function in traditional economics. It projects all Decision-Making Units (DMUs) into a space defined by their inputs and outputs to identify the efficiency frontier. DMUs located on the frontier are considered to have the most efficient input-output combinations, with an efficiency score of 1. DMUs not on the frontier are deemed inefficient, and a relative efficiency score between 0 and 1 is assigned, based on a specific efficient point as a benchmark. Through linear programming, the model calculates the inefficiency values for each inefficient DMU, providing these values as references for future improvements.

The CCR model, developed by Charnes et al. (1978), operates under the assumption of constant returns to scale. To measure the efficiency of a specific decision-making unit $k$k, the efficiency score can be represented by Equation 1.

$$Max\ H_k = \frac{\sum_{r=1}^{s} u_r Y_{rk}}{\sum_{i=1}^{m} v_i x_{ik}} \qquad (1)$$

$$s.t\ \frac{\sum_{r=1}^{s} u_r Y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1 \quad j = 1,2,\dots,n$$

$$u_r \geq \varepsilon > 0 \cdot\ r = 1,2,\dots,s$$

$$v_i \geq \varepsilon > 0 \cdot\ i = 1,2,\dots,m$$

In this context, $H_k$represents the *k* relative efficiency score of the *k*th decision-making unit (DMU). $Y_{rk}$ denotes the *r*th output value for the *k*th DMU, while $X_{ik}$ indicates the *i*th input value for the *k*th DMU. The term $u_r$ refers to the weight assigned to the *r*th output, and $v_i$ signifies the weight assigned to the *i*th input. Since Equation 1 is a fractional linear programming model, which is challenging to solve, the CCR model converts Equation 1 into the linear programming model represented by Equation 2 to facilitate solution. The model is as follows:

$$Max\ H_k = \sum_{r=1}^{s} u_r Y_{rk} \qquad (2)$$

$$s.t \sum_{r=1}^{s} u_r Y_{rj} - \sum_{i=1}^{m} v_i X_{ij} \leq 0 \quad \cdot \quad j = 1,2,\dots,n$$

$$\sum_{i=1}^{m} v_i X_{ik} = 1$$

$$u_r \geq \varepsilon > 0 \ \cdot \quad r = 1,2,\dots,s$$
$$v_i \geq \varepsilon > 0 \ \cdot \quad i = 1,2,\dots,m$$

Banker et al. (1984) extended the CCR model's assumption of constant returns to scale to accommodate variable returns to scale, thereby decomposing technical efficiency into pure technical efficiency (PTE) and scale efficiency (SE) to assess efficiency under different returns to scale conditions. This extended model is commonly referred to as the BCC model. The BCC model is expressed as Equation 3.

In this model, $u_k$ serves as the indicator for returns to scale. When $u_k$>0, it signifies decreasing returns to scale, indicating that the DMU is operating above its optimal scale. When $u_k$=0, it denotes constant returns to scale, meaning the DMU is operating at its optimal scale. When $u_k$<0, it indicates increasing returns to scale, suggesting that the DMU is operating below its optimal scale.

### *3.3.2. Malmquist Productivity Index, MPI*

The previously mentioned CCR model proposed by Charnes et al. (1978) and the BCC model are both designed to measure technical efficiency within a single period. However, Fare, Grosskopf, and Valdmanis (1989) developed the Malmquist Productivity Index (MPI), which allows for the analysis and comparison of efficiency changes over different periods. The MPI decomposes the Total Factor Productivity (TFP) index into two components: Efficiency Change (EC) and Technical Change (TC), addressing the issue of intertemporal efficiency. This method is therefore used to examine the changes in technology and Total Factor Productivity (TFP) for the same DMU across different periods.

According to the definition of the output-oriented Malmquist Productivity Index proposed by Caves, Christensen, and Diewert (1982), the MPI for periods $t$ and $t$+1 is defined as follows:

$$M_0^t = \frac{D_0^t(X^{t+1}, Y^{t+1})}{D_0^t(X^t, Y^t)} \qquad (3)$$

$$M_0^{t+1} = \frac{D_0^{t+1}(X^{t+1}, Y^{t+1})}{D_0^t(X^t, Y^t)} \qquad (4)$$

In the equations, $x_t$ represents the inputs for period *t*, $y_t$ denotes the outputs for period *t*, and $d^t$ is the distance function for period *t*. Färe et al. (1994) extended the MPI defined by Caves et al. (1982) by incorporating the geometric mean to compute changes in TFP over different periods. This is expressed as follows.

$$TFP = M_0(X^{t+1}, Y^{t+1}, X^t, Y^t) = \left[\frac{D_0^t(X^{t+1}, Y^{t+1})}{D_0^t(X^t, Y^t)} \frac{D_0^{t+1}(X^{t+1}, Y^{t+1})}{D_0^{t+1}(X^t, Y^t)}\right]^{\frac{1}{2}} \qquad (5)$$

In the equations, $d_i^t$ denotes the distance function for inputs in period *i*, while $d_i^{t+1}$ represents the distance function for inputs in period *i*+1. A TFP index greater than 1 indicates an improvement in the productivity of the evaluated Decision-Making Unit (DMU); conversely, a TFP index less than 1 signifies a decline in productivity. A TFP index equal to 1 denotes no change in productivity.

## 4. EMPIRICAL RESULTS

Observing the means, the post-the third-generation banking transformation (Bank 3.0) period shows higher averages for all variables except for operating expenses and interest income, which declined. The reduction in operating expenses suggests that following the implementation of the third-generation banking transformation (Bank 3.0), the banking industry leveraged financial technology to offer more diversified and innovative services, thereby improving profitability. Notably, interest expenses decreased by approximately 30%, likely due to the central bank's gradual interest rate cuts following the 2008 financial crisis. For a detailed descriptive statistical analysis of input and output variables, please refer to Tables 2 and 3.

**Table 2.** Descriptive statistics for the pre-third-generation banking transformation (Bank 3.0) period.

| Variable | Mean | Standard deviation | Minimum | Maximum |
|---|---|---|---|---|
| Net Income (NT$ thousands) | 5,717,897 | 6,206,744 | 0.01 | 34,100,000 |
| Average Output per Employee (NT$ thousands) | 1,437 | 1,040 | 0.01 | 8,158 |
| Interest Income (NT$ thousands) | 8,364,542 | 8,650,281 | 49,957 | 43,900,000 |
| Corporate Age (Years) | 33 | 22 | 1 | 93 |
| Total Assets (NT$ thousands) | 806,000,000 | 789,000,000 | 32,800,000 | 3,960,000,000 |
| Shareholders' Equity (NT$ thousands) | 47,800,000 | 47,800,000 | 2,139,495 | 252,000,000 |
| Number of Employees (persons) | 3,721 | 2,617 | 102 | 10,810 |
| Operating Expenses (NT$ thousands) | 3,113,090 | 2,848,801 | 30,364 | 16,400,000 |

**Table 3.** Descriptive Statistics for the Post-the third-generation banking transformation (Bank 3.0) Period.

| Variable | Mean | Standard deviation | Minimum | Maximum |
|---|---|---|---|---|
| Net Income (NT$ thousands) | 5,849,967 | 5,384,589 | 146,918 | 31,100,000 |
| Average Output per Employee (NT$ thousands) | 1,485 | 1,250 | 143 | 18,021 |
| Interest Income (NT$ thousands) | 6,457,668 | 6,395,487 | 210,152 | 33,200,000 |
| Corporate Age (years) | 41 | 22 | 6 | 103 |
| Total Assets (NT$ thousands) | 1,260,000,000 | 1,160,000,000 | 50,100,000 | 5,160,000,000 |
| Shareholders' Equity (NT$ thousands) | 85,100,000 | 78,200,000 | 4,534,197 | 378,000,000 |
| Number of Employees (persons) | 4,173 | 3,230 | 161 | 15,530 |
| Operating Expenses (NT$ thousands) | 3,080,387 | 2,818,257 | 94,677 | 15,300,000 |

To rigorously assess whether the observed differences in performance before and after the implementation of the third-generation banking transformation (Bank 3.0) are statistically significant, we conducted independent sample t-tests on two representative variables: Interest Income and Total Assets. These variables are core indicators of banking operations and financial scale.

The t-test results reveal that both variables exhibit statistically significant differences in their mean values between the pre- and post-the third-generation banking transformation (Bank 3.0) periods. In particular, total assets increased substantially after 2011, reflecting the expansion of bank balance sheets and intensified digital transformation following the adoption of the Bank 3.0 frameworks. The p-values for these comparisons are below the conventional 5% significance level, indicating that the differences are not due to random variation but are instead likely driven by structural and technological changes within the banking sector. These findings support the hypothesis that the third-generation banking transformation (Bank 3.0) has brought measurable shifts in financial outcomes and resource mobilization across Taiwanese banks.

To further validate the robustness of our statistical analysis, we examined the distribution of the key variables using boxplot diagnostics. The visual results clearly identify the presence of high-end outliers in both the Interest

Income and Total Assets distributions during the pre- and post-the third-generation banking transformation (Bank 3.0) periods. These extreme values are typically associated with a few large-scale banks whose operations and revenue-generating capabilities significantly exceed those of their peers. For instance, some banks demonstrate exceptionally high interest income or asset holdings, which may skew the overall mean and reduce the representativeness of central tendency statistics.

To address this concern, we applied winsorization at the 1st and 99th percentiles, as described in the methodology section, to minimize the distortion caused by such outliers. This treatment ensures that our descriptive statistics and inferential tests reflect the general trend of the industry rather than being disproportionately influenced by a small number of dominant institutions. Moreover, the recognition of outliers provides meaningful insights into industry heterogeneity, suggesting that while most banks benefit from the third-generation banking transformation (Bank 3.0) to varying degrees, a few institutions may experience outsized advantages due to superior digital infrastructure or earlier adoption of fintech innovations. For the boxplot diagnostics, please refer to Figure 1 and Figure 2.

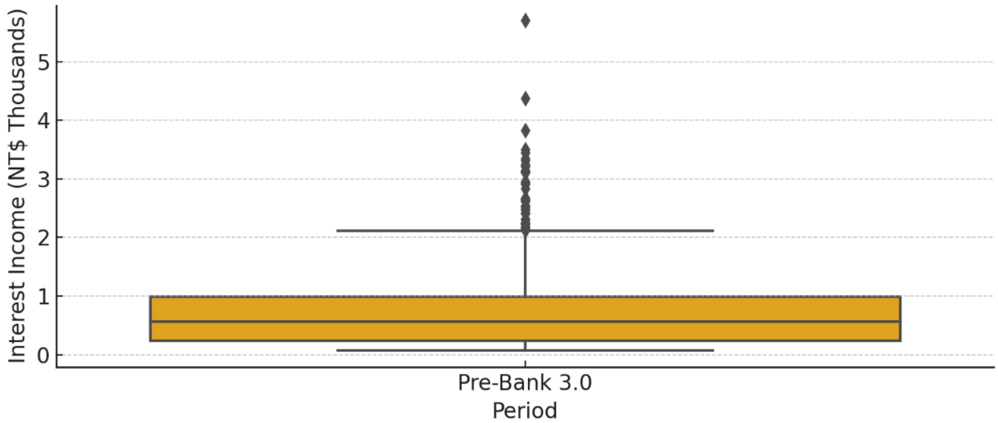


**Figure 1.** Boxplot of interest income (Pre vs. Post the third-generation banking transformation (Bank 3.0)).

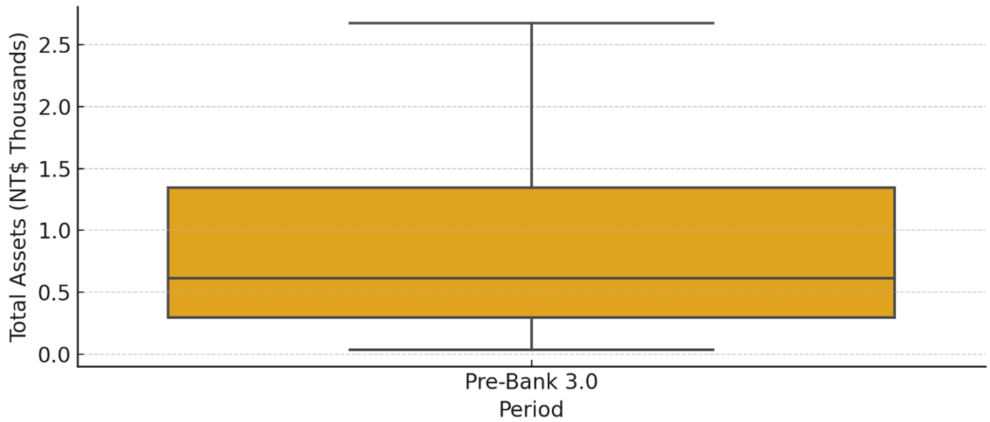


**Figure 2.** Boxplot of total assets (Pre vs. Post the third-generation banking transformation (Bank 3.0)).

### *4.1. Pearson Correlation Analysis*

When employing DEA for evaluation, it is crucial to adhere to certain restrictions imposed by the method. The choice of input and output variables can significantly impact the efficiency scores, and there must be high homogeneity among the entities being evaluated. Additionally, the selected inputs and outputs must exhibit directional consistency. Therefore, this study conducted Pearson correlation tests on the chosen input and output variables. The results of the Pearson correlation analysis indicate that the three selected output variables and five input variables are positively correlated. This suggests that the chosen input and output variables are reasonable and appropriate for analysis using DEA. For details on the Pearson correlation analysis, refer to Tables 4 and 5.

**Table 4.** Pearson correlation analysis for the pre-third-generation banking transformation (Bank 3.0) period.

| Output variables/Input variables | Net Income | Employee Productivity | Interest Income |
|---|---|---|---|
| Corporate age | 0.3215 | 0.100 | 0.3306 |
| Total assets | 0.6256 | 0.1778 | 0.700 |
| Shareholders' equity | 0.6157 | 0.2538 | 0.6891 |
| Employees | 0.7604 | 0.1349 | 0.7351 |
| Operating expenses | 0.9377 | 0.4611 | 0.8985 |

**Table 5.** Pearson correlation analysis for the post-third-generation banking transformation (Bank 3.0) period.

| Output variables/Input variables | Net Income | Employee Productivity | Interest Income |
|---|---|---|---|
| Corporate age | 0.3874 | 0.0969 | 0.4416 |
| Total assets | 0.8873 | 0.0895 | 0.9199 |
| Shareholders' equity | 0.8947 | 0.0794 | 0.8801 |
| Employees | 0.8870 | 0.0867 | 0.7477 |
| Operating expenses | 0.9590 | 0.0594 | 0.8786 |

### *4.2. Empirical Results of DEA*

Table 6 presents the DEA (Data Envelopment Analysis) estimated efficiency values of banks during the pre-third-generation banking transformation (Bank 3.0) period. Observing the total technical efficiency, 15 banks, including E.SUN Commercial Bank, have a total technical efficiency less than 1, indicating relative inefficiency and wastage of input factors. In terms of scale returns, 19 banks, including Yuanta Commercial Bank, show increasing returns to scale, suggesting that the rate of output increase is higher than the rate of input increase. Therefore, these banks could enhance efficiency by increasing input factors and expanding scale. Out of all banks, 18 banks, including Shanghai Commercial & Savings Bank, have the highest total technical efficiency values, accounting for 52.9% of all firms.

**Table 6.** Estimated DEA efficiency of the banking industry in the pre-third-generation banking transformation (Bank 3.0).

| Bank | Total technical efficiency | Pure technical efficiency | Scale efficiency | Scale returns | Ranking |
|---|---|---|---|---|---|
| Shanghai Commercial and Savings Bank | 1 | 1 | 1 | Crs | 1 |
| Taiwan Cooperative Bank | 1 | 1 | 1 | Crs | 1 |
| O-Bank | 1 | 1 | 1 | Crs | 1 |
| Taichung Commercial Bank | 1 | 1 | 1 | Crs | 1 |
| Taipei Fubon Commercial Bank | 1 | 1 | 1 | Crs | 1 |
| Taishin International Bank | 1 | 1 | 1 | Crs | 1 |
| Agricultural Bank of Taiwan | 1 | 1 | 1 | Crs | 1 |
| Hwa Tai Bank | 1 | 1 | 1 | Crs | 1 |
| Hua Nan Commercial Bank | 1 | 1 | 1 | Crs | 1 |
| Sunny Bank | 1 | 1 | 1 | Crs | 1 |
| Shin Kong Bank | 1 | 1 | 1 | Crs | 1 |
| Taiwan Business Bank | 1 | 1 | 1 | Crs | 1 |
| Bank of Taiwan | 1 | 1 | 1 | Crs | 1 |
| Yuanta Commercial Bank | 1 | 0.999 | 0.999 | Irs | 2 |
| JihSun International Commercial | 1 | 0.999 | 0.999 | Irs | 2 |

| Bank | Total technical efficiency | Pure technical efficiency | Scale efficiency | Scale returns | Ranking |
|---|---|---|---|---|---|
| Bank | | | | | |
| Bank SinoPac | 1 | 0.989 | 0.989 | Irs | 3 |
| Bank of Panhsin | 1 | 0.978 | 0.978 | Irs | 4 |
| Chang Hwa Commercial Bank | 1 | 0.978 | 0.978 | Irs | 4 |
| E.SUN Commercial Bank | 0.992 | 0.981 | 0.989 | Irs | 5 |
| First Commercial Bank | 0.967 | 0.966 | 1 | Crs | 6 |
| San Hsin Commercial Bank | 0.967 | 0.966 | 1 | Crs | 6 |
| Mega International Commercial Bank | 0.965 | 0.957 | 0.991 | Irs | 7 |
| CTBC Bank | 0.907 | 0.906 | 0.999 | Irs | 8 |
| Export-Import Bank of the Republic of China (Taiwan) | 0.907 | 0.906 | 0.999 | Irs | 8 |
| Cooperative Bank of Taiwan | 0.844 | 0.826 | 0.978 | Irs | 9 |
| KGI Bank | 0.834 | 0.819 | 0.981 | Irs | 10 |
| Standard Chartered Bank (Taiwan) | 0.8 | 0.789 | 0.986 | Irs | 11 |
| Bank of Panhsin | 0.787 | 0.775 | 0.985 | Irs | 12 |
| Bank of Kaohsiung | 0.765 | 0.748 | 0.978 | Irs | 13 |
| King's Town Bank | 0.751 | 0.732 | 0.974 | Irs | 14 |
| Cathay United Bank | 0.736 | 0.723 | 0.983 | Irs | 15 |
| Entie Commercial Bank | 0.69 | 0.676 | 0.98 | Irs | 16 |
| Far Eastern International Bank | 0.553 | 0.52 | 0.941 | Irs | 17 |
| Union Bank of Taiwan | 0.553 | 0.52 | 0.941 | Irs | 17 |
| Average | 0.912 | 0.904 | 0.990 | | |

**Note:** Crs, Irs, and Drs represent constant returns to scale, increasing returns to scale, and decreasing returns to scale, respectively.

Table 7 presents the DEA (Data Envelopment Analysis) estimated efficiency values of banks during the post-the third-generation banking transformation (Bank 3.0) period. Observing the total technical efficiency, 19 banks, including Taiwan Bank, have a total technical efficiency less than 1, indicating relative inefficiency and wastage of input factors. In terms of scale returns, 20 banks, including First Commercial Bank, show increasing returns to scale, suggesting that the rate of output increase is higher than the rate of input increase. Therefore, these banks could enhance efficiency by increasing input factors and expanding scale. Fifteen banks, including Sanxin Commercial Bank, have the highest total technical efficiency values, accounting for 44.1% of all firms.

Comparing the DEA efficiency values before and after the third-generation banking transformation (Bank 3.0), the data show that the post-transformation DEA efficiency value of 0.981 is significantly better than the pre-transformation value of 0.912. This indicates that most banks, after investing in relevant financial technologies and entering the next phase of technology application, have indeed improved their efficiency. This is supported by concrete data, such as First Bank, which achieved an efficiency value of 1 in the later period and ranks among the top two banks in terms of financial patents according to patent databases. During the third-generation banking transformation (Bank 3.0) era, First Bank demonstrated significant progress in both the number of financial patents it secured and its growth in financial technology. Taiwan initiated aggressive financial technology development policies in 2015, relaxing investment restrictions for banks in fintech companies, allowing them to hold 100% ownership in these firms. These policies accelerated investment in financial technology innovations across Taiwanese banks, fostering collaborations between banks and fintech companies to develop new technologies.

As one of Taiwan's leading banks, First Bank actively participated in this trend, focusing on patents related to payment systems, data management, and digital financial services. With the rapid growth of the fintech sector, First Bank significantly increased its patent portfolio, especially in areas such as digital payments and blockchain technology. These efforts allowed First Bank to strengthen its competitive position within the banking industry and drive the development of its fintech division, enhancing its competitiveness in both domestic and international markets. Through these patents and technological innovations, First Bank not only improved service efficiency but also enhanced customer experience, further solidifying its market position.

**Table 7.** Estimated DEA efficiency of the banking industry in the Post-the third-generation banking transformation (Bank 3.0).

| Bank | Total technical efficiency | Pure technical efficiency | Scale efficiency | Scale returns | Ranking |
|---|---|---|---|---|---|
| San Hsin Commercial Bank | 1 | 1 | 1 | Crs | 1 |
| Land Bank of Taiwan | 1 | 1 | 1 | Crs | 1 |
| E.SUN Commercial Bank | 1 | 1 | 1 | Crs | 1 |
| Bank SinoPac | 1 | 1 | 1 | Crs | 1 |
| Mega International Commercial Bank | 1 | 1 | 1 | Crs | 1 |
| Yung-Fa Commercial Bank | 1 | 1 | 1 | Crs | 1 |
| Shin Kong Bank | 1 | 1 | 1 | Crs | 1 |
| Taiwan Business Bank | 1 | 1 | 1 | Crs | 1 |
| Far Eastern International Bank | 1 | 1 | 1 | Crs | 1 |
| Federal Bank | 1 | 1 | 1 | Crs | 1 |
| First Commercial Bank | 1 | 0.994 | 0.994 | Irs | 2 |
| Chang Hwa Bank | 1 | 0.987 | 0.987 | Irs | 3 |
| Bank of China (Taiwan) | 1 | 0.971 | 0.971 | Irs | 4 |
| Yuanta Commercial Bank | 1 | 0.97 | 0.97 | Irs | 5 |
| Shanghai Commercial & Savings Bank | 1 | 0.926 | 0.926 | Irs | 6 |
| Bank of Taiwan | 0.995 | 0.976 | 0.981 | Irs | 7 |
| Fubon Bank (Taipei) | 0.992 | 0.982 | 0.99 | Irs | 8 |
| Kaohsiung Bank | 0.989 | 0.985 | 0.995 | Irs | 9 |
| Rising Bank | 0.987 | 0.984 | 0.997 | Irs | 10 |
| National Agricultural Bank | 0.986 | 0.98 | 0.993 | Irs | 11 |
| CTBC Bank | 0.985 | 0.963 | 0.978 | Irs | 12 |
| Hua Nan Bank | 0.975 | 0.974 | 0.999 | Drs | 13 |
| KGI Bank | 0.972 | 0.954 | 0.982 | Irs | 14 |
| Jih Sun International Bank | 0.971 | 0.938 | 0.966 | Irs | 15 |
| Taipei Fubon Bank | 0.965 | 0.964 | 1 | Crs | 16 |
| Chengdu Commercial Bank | 0.961 | 0.956 | 0.995 | Irs | 17 |
| O-Bank | 0.96 | 0.93 | 0.968 | Irs | 18 |
| Taishin International Bank | 0.956 | 0.956 | 1 | Crs | 19 |
| Antai Commercial Bank | 0.954 | 0.954 | 1 | Crs | 20 |
| Banqiao Commercial Bank | 0.952 | 0.942 | 0.989 | Irs | 21 |
| Taichung Commercial Bank | 0.948 | 0.94 | 0.992 | Irs | 22 |
| Cathay United Bank | 0.943 | 0.941 | 0.997 | Irs | 23 |
| Hua Tai Bank | 0.936 | 0.933 | 0.997 | Irs | 24 |
| Standard Chartered Bank | 0.931 | 0.928 | 0.997 | Irs | 25 |
| Average | 0.981 | 0.971 | 0.99 | | |

**Note:** Crs, Irs, and Drs represent constant returns to scale, increasing returns to scale, and decreasing returns to scale, respectively.

### *4.3. Empirical Results of Model 2*

Table 8 presents the empirical results of the MPI for the banking industry in the pre-third-generation banking transformation (Bank 3.0) era. From Table 8, it can be observed that the Total Factor Productivity Change (TFPCH) for 41.2% of the 34 companies is greater than 1, indicating positive productivity growth. Conversely, 58.8% of the companies have a TFPCH less than 1. The industry average is 0.938. The top three performers are Far Eastern International Bank, Union Bank of Taiwan, and Chang Hwa Commercial Bank. This indicates that more than two-fifths of the industry's enterprises are experiencing productivity growth, with the lowest performer achieving a TFPCH of 0.715.

**Table 8.** Empirical results of the banking industry's MPI in the pre-third-generation banking transformation (Bank 3.0).

| Bank | EFFCH | TECH | PTECH | SECH | TFPCH | TFPCH Ranking |
|---|---|---|---|---|---|---|
| Far Eastern International Bank | 1.018 | 1.31 | 1.019 | 1 | 1.334 | 1 |
| Union Bank of Taiwan | 1.01 | 1.31 | 1.012 | 0.999 | 1.323 | 2 |
| Chang Hwa Commercial Bank | 0.99 | 1.245 | 0.997 | 0.992 | 1.232 | 3 |
| Bank of Taiwan | 0.995 | 1.232 | 1 | 0.995 | 1.226 | 4 |
| Taishin International Bank | 0.992 | 1.234 | 1 | 0.992 | 1.223 | 5 |
| Taiwan Business Bank | 0.986 | 1.209 | 0.99 | 0.996 | 1.193 | 6 |
| Shin Kong Commercial Bank | 0.983 | 1.15 | 0.995 | 0.987 | 1.13 | 7 |
| Sunny Bank | 0.996 | 1.125 | 1 | 0.996 | 1.12 | 8 |
| Hua Nan Commercial Bank | 0.996 | 1.084 | 1 | 0.996 | 1.079 | 9 |
| Standard Chartered Bank (Taiwan) | 1.01 | 1.06 | 1.01 | 1.001 | 1.071 | 10 |
| KGI Bank | 1.005 | 1.062 | 1.005 | 1 | 1.067 | 11 |
| Hwatai Bank | 0.996 | 1.064 | 0.999 | 0.997 | 1.06 | 12 |
| Bank of Kaohsiung | 1.013 | 1.045 | 1.012 | 1.001 | 1.059 | 13 |
| Cathay United Bank | 1.014 | 1.028 | 1.013 | 1.001 | 1.043 | 14 |
| King's Town Bank | 1.014 | 0.976 | 1.013 | 1.001 | 0.989 | 15 |
| Bank of Panhsin | 1.011 | 0.977 | 1.01 | 1.001 | 0.988 | 16 |
| Taiwan Cooperative Bank | 1.008 | 0.944 | 1.007 | 1.001 | 0.952 | 17 |
| EnTie Commercial Bank | 1.017 | 0.906 | 1.016 | 1.001 | 0.921 | 18 |
| Mega International Commercial Bank | 1.002 | 0.88 | 1.002 | 1 | 0.882 | 19 |
| Bank SinoPac | 1 | 0.864 | 1 | 1 | 0.865 | 20 |
| Agricultural Bank of Taiwan | 1 | 0.861 | 1 | 1 | 0.861 | 21 |
| E.Sun Commercial Bank | 1.001 | 0.85 | 1 | 1 | 0.851 | 22 |
| Taipei Fubon Commercial Bank | 1 | 0.827 | 1 | 1 | 0.827 | 23 |
| Taishin International Bank | 1 | 0.818 | 1 | 1 | 0.818 | 24 |
| Taichung Commercial Bank | 1 | 0.761 | 1 | 1 | 0.761 | 25 |
| O-Bank | 0.99 | 0.767 | 0.99 | 1 | 0.759 | 26 |
| Land Bank of Taiwan | 0.995 | 0.759 | 1 | 0.995 | 0.755 | 27 |
| Yuanta Commercial Bank | 0.997 | 0.755 | 0.998 | 0.999 | 0.753 | 28 |
| Shanghai Commercial and Savings Bank | 0.998 | 0.749 | 1 | 0.998 | 0.748 | 29 |
| Jih Sun International Commercial Bank | 0.99 | 0.752 | 0.99 | 1 | 0.745 | 30 |
| CTBC Bank | 1.004 | 0.739 | 1.004 | 1 | 0.743 | 31 |
| First Commercial Bank | 0.999 | 0.722 | 1.001 | 0.998 | 0.721 | 32 |
| San Hsin Commercial Bank | 0.994 | 0.72 | 1.001 | 0.993 | 0.716 | 33 |
| Export-Import Bank of the Republic of China | 0.989 | 0.722 | 0.994 | 0.995 | 0.715 | 34 |
| Average | 1.000 | 0.938 | 1.002 | 0.998 | 0.938 | |

**Note:** EFFCH, TECH, PTECH, SECH, and TFPCH represent efficiency change, technical efficiency, pure technical efficiency, scale efficiency, and total factor productivity change, respectively.

Table 9 presents the empirical results of the MPI for the banking industry in the post-the third-generation banking transformation (Bank 3.0) era. From Table 9, it is observed that the Total Factor Productivity Change (TFPCH) is greater than 1 for approximately 53% of the 34 companies, while 47% have a TFPCH less than 1. The industry average is 1.012. The top three performers are Union Bank of Taiwan, Bank of Taiwan, and Taiwan Business Bank. This indicates that half of the industry's enterprises are experiencing productivity growth, with the lowest performer achieving a TFPCH of 0.693. Compared to the pre-the third-generation banking transformation (Bank 3.0) era, there has been a significant improvement in Total Factor Productivity, with a noticeable increase in the number of companies with a TFPCH greater than 1.

Comparing the MPI productivity growth between the pre-third-generation banking transformation (Bank 3.0) and the post-third-generation banking transformation (Bank 3.0) periods, data shows an increase from 0.938 in the pre-third-generation banking transformation (Bank 3.0) era to 1.012 in the post-third-generation banking transformation (Bank 3.0) era, indicating substantial growth. This suggests that with the transition to the third-generation banking transformation (Bank 3.0), banks have invested more in financial technology. This investment not only provided more innovative services but also contributed to enhanced productivity for enterprises.

For example, in recent years, King's Town Bank has actively embraced digital transformation in response to the rise of financial technology. The launch of the "Goyee Digital Account" marks a significant strategic shift for the bank. Traditionally, the bank promoted its corporate finance, investment, deposits, and wealth management services through face-to-face interactions. However, with the development of digital channels, the bank aimed to offer more comprehensive services to its customers, thereby creating unique value. This strategic change has resulted in a significant improvement in productivity. The push towards digitalization has enabled King's Town Bank to streamline operations, reduce costs associated with physical branches, and enhance customer engagement by offering convenient 24/7 banking services. Additionally, the implementation of digital tools and platforms has allowed the bank to more effectively collect and analyze customer data, leading to more targeted services and products, which in turn has contributed to overall performance improvement. As a result, the bank has not only expanded its customer base but also increased its operational efficiency, aligning with the core objectives of the third-generation banking transformation (Bank 3.0) era.

**Table 9.** Empirical results of the banking industry's MPI in the Post-the third-generation banking transformation (Bank 3.0).

| Bank | EFFCH | TECH | PTECH | SECH | TFPCH | TFPCH Ranking |
|---|---|---|---|---|---|---|
| Union Bank of Taiwan | 1 | 1.439 | 1 | 1 | 1.439 | 1 |
| Bank of Taiwan | 1.001 | 1.391 | 1 | 1.001 | 1.392 | 2 |
| Taiwan Business Bank | 1 | 1.379 | 1 | 1 | 1.379 | 3 |
| Far Eastern International Bank | 1 | 1.362 | 1 | 1 | 1.362 | 4 |
| Chang Hwa Commercial Bank | 1 | 1.32 | 1 | 1 | 1.321 | 5 |
| Taishin International Bank | 1 | 1.295 | 1 | 1 | 1.296 | 6 |
| Shin Kong Commercial Bank | 1 | 1.263 | 1 | 1 | 1.262 | 7 |
| Sunny Bank | 0.999 | 1.257 | 0.999 | 1 | 1.255 | 8 |
| Hua Nan Commercial Bank | 1.001 | 1.243 | 1.001 | 1 | 1.244 | 9 |
| Hwatai Bank | 1.001 | 1.161 | 1.001 | 1 | 1.162 | 10 |
| Standard Chartered Bank (Taiwan) | 1 | 1.114 | 1.001 | 1 | 1.114 | 11 |
| KGI Bank | 1 | 1.105 | 1 | 1 | 1.105 | 12 |
| Cathay United Bank | 1.002 | 1.075 | 1.002 | 1 | 1.077 | 13 |
| Bank of Kaohsiung | 0.999 | 1.066 | 0.999 | 0.999 | 1.065 | 14 |
| King's Town Bank | 1 | 1.053 | 1 | 1 | 1.054 | 15 |
| Bank of Panhsin | 1 | 1.044 | 1 | 1 | 1.044 | 16 |
| EnTie Commercial Bank | 1 | 1.024 | 1 | 1 | 1.023 | 17 |
| Taiwan Cooperative Bank | 1 | 1.01 | 1 | 1 | 1.01 | 18 |
| Mega International Commercial Bank | 1 | 0.984 | 1 | 1 | 0.984 | 19 |
| E.Sun Commercial Bank | 1 | 0.975 | 1 | 1 | 0.975 | 20 |
| Agricultural Bank of Taiwan | 0.999 | 0.969 | 0.999 | 1 | 0.968 | 21 |
| Bank SinoPac | 0.999 | 0.965 | 1 | 1 | 0.965 | 22 |
| Taipei Fubon Commercial Bank | 0.999 | 0.902 | 0.999 | 1 | 0.901 | 23 |
| Taishin International Bank | 1.001 | 0.899 | 1.001 | 1 | 0.899 | 24 |
| Taichung Commercial Bank | 1.001 | 0.886 | 1.001 | 1 | 0.887 | 25 |
| O-Bank | 1.001 | 0.867 | 1.001 | 1.001 | 0.868 | 26 |
| Jih Sun International Commercial Bank | 1.001 | 0.845 | 1 | 1.001 | 0.846 | 27 |
| Yuanta Commercial Bank | 1.001 | 0.81 | 1 | 1.001 | 0.811 | 28 |
| Export-Import Bank of the Republic of China | 1.001 | 0.792 | 1 | 1.001 | 0.792 | 29 |
| CTBC Bank | 1.001 | 0.78 | 1 | 1.001 | 0.78 | 30 |
| Land Bank of Taiwan | 1 | 0.759 | 1 | 1 | 0.759 | 31 |
| Shanghai Commercial and Savings Bank | 1.002 | 0.726 | 1 | 1.002 | 0.727 | 32 |
| San Hsin Commercial Bank | 1 | 0.701 | 1 | 1 | 0.701 | 33 |
| First Commercial Bank | 1 | 0.693 | 1 | 1 | 0.693 | 34 |
| Average | 1 | 1.012 | 1 | 1 | 1.012 | |

**Note:** EFFCH, TECH, PTECH, SECH, and TFPCH represent efficiency change, technical efficiency, pure technical efficiency, scale efficiency, and total factor productivity change, respectively.

### *4.4. Combined Analysis of DEA Total Technical Efficiency and MPI Total Factor Productivity Change*

Using an XY scatter plot, where total technical efficiency is plotted on the X-axis and Total Factor Productivity Change (TFPCH) is plotted on the Y-axis, and incorporating the mean values as dividing lines, a quadrant diagram is formed. The characteristics of each quadrant are as follows:

A. First Quadrant (High Competitiveness and Rapid Growth)

Firms located in the first quadrant exhibit high efficiency and high productivity, indicating sound management practices and a competitive edge, as well as potential for further improvement. These firms serve as benchmarks for inefficient firms to learn from and compare against.

B. Second Quadrant (Low Competitiveness and Rapid Growth)

Firms in the second quadrant display low efficiency but high productivity, suggesting a need for clearer management direction and practices to maintain competitiveness, though they are experiencing rapid progress.

C. Third Quadrant (Low Competitiveness and Slow Growth)

Firms in the third quadrant show low efficiency and low productivity, indicating a need for more defined management strategies and practices, coupled with a need to accelerate their progress.

D. Fourth Quadrant (High Competitiveness and Slow Growth)

Firms in the fourth quadrant demonstrate high efficiency but low productivity, suggesting that they should seek new breakthroughs to maintain their competitive advantage while also improving their growth rate.

In the pre-third-generation banking transformation (Bank 3.0) era, the banks located in the first quadrant include Chang Hwa Bank, Sunny Bank, Hua Nan Bank, Bank of Taiwan, Hwatai Bank, Taiwan Business Bank, Shin Kong Bank, and Far Eastern International Bank, totaling 8 banks, which account for 23.5%.

This indicates that these banks possess a strong competitive advantage and can serve as benchmarks for other banks. These public sector banks typically operate under stringent regulatory oversight, ensuring robust risk management practices and high standards of financial stability. They have utilized financial technology to streamline traditional manual operations, thereby reducing operational costs and enhancing service quality.

In the second quadrant, there are 9 banks, representing 26.5%, which exhibit low efficiency but high productivity.

This suggests that these banks need clearer management strategies and practices to maintain their competitiveness. In the fourth quadrant, there are 14 banks, accounting for 41.2%, which display high efficiency but low productivity. These banks should seek new breakthroughs to sustain their competitive advantage. Please refer to Table 10 and Figure 3.

**Table 10.** Number of domestic banks in each quadrant before and after the third-generation banking transformation (Bank 3.0).

| Quadrant | Pre-Bank 3.0 | Post-Bank 3.0 |
|---|---|---|
| First | 8 banks (23.5%) | 9 banks (26.5%) |
| Second | 9 banks (26.5%) | 8 banks (23.5%) |
| Third | 3 banks (8.8%) | 5 banks (14.7%) |
| Fourth | 14 banks (41.2%) | 12 banks (35.3%) |

In the post-the third-generation banking transformation (Bank 3.0) era, the banks located in the first quadrant are Chang Hwa Bank, Taiwan Business Bank, Bank SinoPac, Far Eastern International Bank, Shin Kong Bank, Sunny Bank, Bank of Taiwan, Kaohsiung Bank, and Federal Bank, totaling 9 banks, which represent 26.5%. This indicates that these banks possess a strong competitive advantage and can serve as benchmarks for other banks.

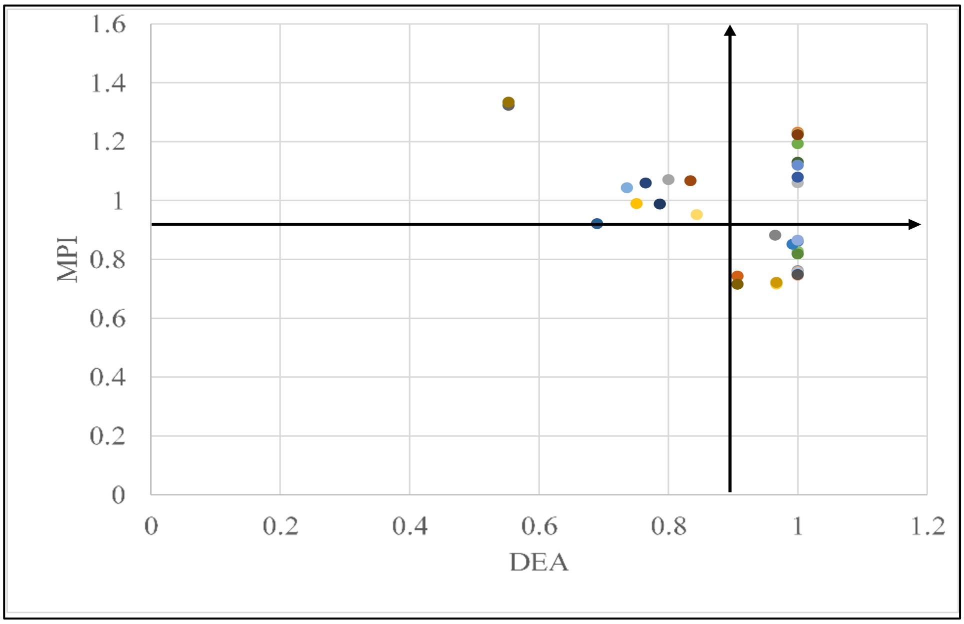


**Figure 3.** Combined analysis of DEA and MPI in the pre-third-generation banking transformation (Bank 3.0).

In the second quadrant, there are 8 banks, representing 23.5%, which exhibit low efficiency but high productivity. This suggests that these banks need clearer management strategies and practices to maintain their competitiveness. Please refer to Table 10 and Figure 4.

The combined analysis of efficiency and productivity indices before and after the third-generation banking transformation (Bank 3.0) reveals that in the pre-Bank 3.0 era, Hwatai Bank and Hua Nan Bank were positioned in the first quadrant, indicating higher competitiveness within the industry. However, in the post-Bank 3.0 era, these banks have fallen into the second quadrant due to a decline in total technical efficiency, suggesting a need for more defined management strategies and practices. Conversely, in the post-third-generation banking transformation (Bank 3.0) era, SinoPac Federal Bank, Far Eastern International Bank, and Kaohsiung Bank have rapidly risen in the ranks due to improvements in total technical efficiency, advancing from the second quadrant to the first quadrant and successfully enhancing their competitive advantage. This highlights that efficiency has a significant impact on a bank's ability to enhance its competitiveness.

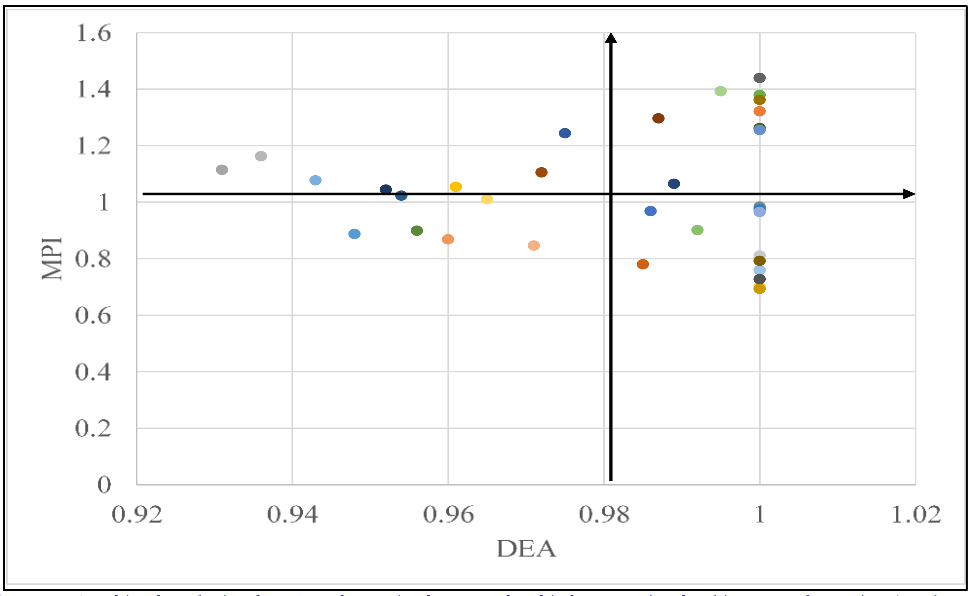


**Figure 4.** Combined analysis of DEA and MPI in the Post-the third-generation banking transformation (Bank 3.0).

## 5. CONCLUSION

Firstly, regarding the empirical results of DEA, the estimated efficiency value for the banking industry in the pre-third-generation banking transformation (Bank 3.0) era was 0.912, while the post-Bank 3.0 era estimated value was 0.981, indicating a gradual improvement in industry efficiency. The banks with optimal total technical efficiency in both periods are Shanghai Commercial & Savings Bank, Bank of Taiwan, Sunny Bank, Shin Kong Bank, Taiwan Business Bank, Yuanta Bank, and Chang Hwa Bank, accounting for 20.6% of all banks.

Secondly, regarding the MPI empirical results, the total factor productivity change (TFPCH) during the pre-third-generation banking transformation (Bank 3.0) era indicated that out of 34 companies, 14 had a TFPCH greater than 1 (41.2%), with an industry average of 0.938. The top three banks were Far Eastern International Bank, SinoPac Bank, and Chang Hwa Bank, suggesting that more than two-fifths of the firms in the industry experienced productivity growth, with the lowest firm reaching 0.715. In the post-third-generation banking transformation (Bank 3.0) era, out of 34 companies, 18 had a TFPCH greater than 1 (53%), with an overall industry average of 1.012. The top three banks were SinoPac Bank, Bank of Taiwan, and Taiwan Business Bank. This demonstrates that half of the industry's firms experienced productivity growth, with the lowest firm achieving 0.693. Compared to the pre-third-generation banking transformation (Bank 3.0) era, there was a significant improvement in total factor productivity, and the number of firms with TFPCH greater than 1 has been gradually increasing.

Finally, the comprehensive analysis indicates that the banking industry, after undergoing structural analysis, DEA, and MPI estimation, shows improved performance in both efficiency and productivity in the post-the third-generation banking transformation (Bank 3.0) era compared to the pre-the third-generation banking transformation (Bank 3.0) period. This validates the importance and value of investing in financial technology. Moreover, the combined analysis of DEA total technical efficiency and MPI total factor productivity change reveals that banks should leverage financial technology to enhance efficiency, which has a synergistic effect on productivity and performance improvements.

From a policy perspective, the findings of this study suggest the importance of fostering a responsible and inclusive fintech ecosystem. Policymakers should not only encourage innovation but also support smaller or less digitized banks through targeted subsidies, digital capacity-building programs, and regulatory flexibility, enabling them to compete more effectively in a rapidly transforming banking landscape.

The quadrant analysis also reveals heterogeneity in banks' responses to digital transformation. While some banks have clearly moved into the high-efficiency, high-productivity quadrant, others remain stagnant or have regressed. This underscores the need for differentiated digital strategies based on each bank's operational scale, technological capability, and managerial readiness.

Future research may consider integrating qualitative factors such as digital leadership, organizational culture, and customer acceptance into the analysis. Additionally, longitudinal case studies on successful digital transformation within the banking sector could further enrich the empirical understanding and practical relevance of fintech-driven efficiency dynamics.

## 6. RECOMMENDATIONS

The DEA input variables used in this study suggest that future researchers might explore the use of alternative variables to measure efficiency and compare the differences. For instance, variables such as total deposits, total assets, or loans could be employed. Similarly, output variables could include fee and commission income or loan amounts. This study focuses on the financial industry; thus, it is recommended that future research examine different industries for cross-sector analysis.

In response to the future development of artificial intelligence and digitalization, the government should encourage and support the financial industry in developing related services and applications. For example, blockchain technology offers advantages such as cost reduction, increased transparency, and traceability, which are beneficial for building consumer trust and creating secure, flexible financial products. Additionally, it is important to moderately relax financial regulations to provide traditional banks and future online-only banks with more development flexibility and space. Banks should also offer safer, more convenient, and user-friendly financial technology services. Industry practitioners should promote and educate general users to help consumers or clients easily enjoy the convenience provided by financial technology.

To enhance the relevance of policy suggestions, this study highlights the importance of not only promoting financial innovation but also addressing accompanying governance challenges. Effective data privacy regulations, cybersecurity frameworks, and anti-money laundering mechanisms must be established in parallel to mitigate risks introduced by emerging digital technologies. Furthermore, global alignment in fintech regulatory practices is essential. Taiwan's financial industry should benchmark against international standards such as those set by the Financial Stability Board (FSB) and Basel Committee on Banking Supervision, enabling cross-border digital service compatibility while preserving financial stability.

Recognizing the uneven digital maturity across banks, targeted government programs should be designed to assist small and medium-sized banks in building digital infrastructure and technical capacity. These banks often face resource constraints and regulatory burdens that limit their ability to compete with larger, more technologically advanced institutions. By integrating these balanced and globally contextualized strategies, policymakers can ensure that fintech development proceeds in an inclusive, secure, and sustainable manner, thus amplifying the long-term benefits of the third-generation banking transformation (Bank 3.0) adoption.

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