Efficiency Evaluation of Taiwan's Commercial Banks after IFRS Adoption: A Two-System Network Data Envelopment Approach

Nan-Hsing Hsiung
Department of Business Management, National Taipei University of Technology
1, Sec. 3, Chung-Hsiao E. Rd. Taipei 10608, Taiwan
Email: hsiung8@ntub.edu.tw

Chuang-Min Chao
Department of Business Management, National Taipei University of Technology
No. 1, Sec.3, Chung-hsiao E. Rd, Taipei 10608, Taiwan
E-mail: cmchao@mail.ntut.edu.tw

Ming-Miin Yu[a]
Department of Transportation Science, National Taiwan Ocean University
No.2, Beining Rd., Jhongjheng District, Keelung City 202, Taiwan
E-mail: yumm@mail.ntou.edu.tw

Received: 06 July 2017; Accepted: 29 August 2024.

Abstract: The objective of this study is to assess the operational efficiencies of Taiwanese commercial banks from 2013 to 2022, following the adoption of the International Financial Reporting Standards (IFRS) in 2013. This study introduces an extended non-convex two-system network data envelopment analysis (DEA) model, which decomposes the production process into two sub-processes: profitability and marketability stages. Additionally, the study categorizes eighteen listed commercial banks into two groups based on their affiliation with financial holding companies (FHCs). The results of the Mann-Whitney U test reveal significant differences in both profitability efficiency and marketability efficiency between FHC banks and non-FHC banks. However, the overall efficiency of FHC banks does not differ significantly from that of non-FHC banks during the sample period. The empirical findings indicate that, on average, banks affiliated with FHCs outperform those not affiliated with FHCs in terms of profitability efficiency, with this effect being statistically significant. Conversely, FHC banks exhibit lower marketability efficiency compared to non-FHC banks. These results suggest that while FHC affiliation can enhance profitability efficiency, it may not necessarily improve marketability efficiency.

Key words: Bank efficiency, Network Data Envelopment Analysis, International Financial Reporting Standards, Financial Holding Company.
JEL: G21,G30

[a] Corresponding author

1. Introduction

The financial market plays a fundamental role in facilitating the trading of financial instruments and matching the supply and demand for capital, which is vital for both national and global economic activities. Before 1980, Taiwan's financial sector was largely conservative and monopolized by the public sector. However, in response to rapid economic expansion, the Taiwanese government implemented financial liberalization policies, beginning in 1980, aimed at deregulating the financial system. These measures were intended to enhance capital allocation, boost investment, and accelerate economic development.

The first significant financial reform came in 1990, leading to the establishment of numerous new banks. However, this also resulted in market saturation, as banks competed fiercely, leading to a reduction in lending rates and an increase in deposit rates. By 2000, to address these inefficiencies, the government introduced the Financial Institutions Merger Act to encourage consolidation. The Financial Holding Company (FHC) Act of 2001 further facilitated the integration of financial services (Chiou, 2009), allowing institutions to manage banking, securities, and insurance operations under one umbrella, enhancing operational efficiency.

Over the years, extensive research has analyzed the performance differences between FHC (subsidiaries of FHCs) and non-FHC (individual banks) banks (Chen et al., 2005; Liu et al., 2006; Chiou, 2009; Lin and Lee, 2010; Liu and Hsu, 2014; Chao et al., 2018; Yu et al., 2021), particularly in light of Taiwan's adoption of International Financial Reporting Standards (IFRS) in 2013. The adoption of IFRS, aimed at improving global financial reporting comparability and transparency, has significantly impacted bank performance by influencing asset valuations and profitability (Liu, 2010; Chiu et al., 2011; Juo et al., 2012). The shift to IFRS, with its focus on fair value accounting, affected banks' financial strategies, as reflected in adjustments to loan contracts, investment approaches, and asset measurements (Uyar, 2013; Gabriela and Gabriela, 2012). This reform has reshaped Taiwan's financial landscape and remains a critical area of study, particularly in understanding its effects on the banking sector's profitability and marketability.

Traditional Data Envelopment Analysis (DEA) models have historically treated banking operations as a single process (Färe and Grosskopf, 2000; Sexton and Lewis, 2003; Chen and Zhu, 2004; Wei et al., 2011; Yu et al., 2013; Chiu et al., 2016). However, recent studies suggest that these operations consist of multiple internal stages, particularly in distinguishing between profitability and marketability (Seiford and Zhu, 1999). As a result, non-parametric network structures have gained popularity for analyzing bank performance (Zhu, 2000; Luo, 2003; Lo and Lu, 2006; Zhu et al., 2014; Nagaraju, 2014; Chao et al., 2018; Rakshit, 2021), especially for distinguishing between FHC banks and non-FHC banks. FHC banks may benefit from cost reductions and cross-selling synergies, unlike non-FHC banks, which operate independently (Lee et al., 2013). Given the structural differences between FHC and non-FHC banks, and the impact of IFRS adoption, this study employs a two-system network DEA (NDEA) model with a non-convex meta-frontier framework. By analyzing financial data from

2013 to 2022, the study aims to identify performance gaps between the two types of banks, providing insights into their respective efficiencies and highlighting areas for strategic improvement.

This paper is structured as follows: Section 2 reviews the relevant literature, Section 3 outlines the methodology, Section 4 presents the data and empirical results, and Section 5 concludes with key findings and implications.

2. Literature Review

2.1 IFRS in Taiwan

Taiwan adopted IFRS in 2013. In fact, Taiwan's financial accounting standards (TFAS) had been gradually converging towards IFRS since 1999. For instance, TFAS No. 14, introduced in 2006, utilized fair value to measure financial assets. Additionally, from 2011, further IFRS were adopted for classifying accounts receivable as financial assets. Chao et al. (2015) examined the impact of IFRS adoption on the efficiencies of Taiwanese banks in 2012, finding that IFRS adoption led to statistically significant differences in both profitability and marketability efficiencies of Taiwanese commercial banks. In 2009, the Taiwanese government mandated the adoption of IFRS by 2013. Consequently, both FHC banks and non-FHC banks began adjusting their operational strategies to mitigate the impact of the new standards. Despite the completion of accounting standards conversion in 2013, there remains a gap in research regarding the post-adoption effects. To address this, Chao et al. (2018) employed a convex meta-frontier approach using financial data from Taiwanese commercial banks in the first year (2013) of IFRS adoption to measure the profitability and marketability efficiencies of these banks.

2.2 Bank Performance using DEA Approach

Since the 1990s, Taiwan has undergone deregulation and consolidation reforms in its financial industry, leading to a growing body of research on bank operational efficiency. For example, Liu et al. (2014) studied post-financial-reconstruction operational efficiency, while Chen (2002) and Liu (2013) explored the relationship between bank equity structure and operational efficiency in publicly and privately operated banks. Liu et al. (2014) found that old commercial banks (established before 1990) exhibit higher overall technical, pure technical, and allocative efficiency compared to new banks (established after 1990) and those upgraded from credit cooperatives. Chen (2002) concluded that publicly owned banks perform better in profitability, whereas privately owned banks have superior operational capabilities. Liu (2013) found that privatization through government share releases improved bank operational efficiency.

Further studies investigated efficiency differences between new and old banks in Taiwan. Liu (2010) noted varying patterns in technical efficiency and productivity changes among different types of commercial banks over time. Chiu et al. (2011) examined the impact of account risk on technical efficiency from 1998 to 2002, while

Juo et al. (2012) analyzed profit changes in Taiwanese banks from the early 1990s to the early 2000s, noting significant differences in profit components between public and private banks. After the FHC Act took effect in 2001, research focused on the efficiencies of cross-selling synergies and operational issues in Taiwanese FHCs (e.g., Lo and Lu, 2006; Chiou, 2009; Chao et al., 2010; Chen et al., 2010; Liu, 2011; Kao et al., 2012; Guo and Yang, 2013; Chen and Kao, 2014; Liu and Hsu, 2014; Zhu et al., 2014; Kong et al., 2017; Yu et al., 2021).

Despite the goal of financial consolidation to enhance competition and efficiency, research on the impact of financial reforms on Taiwan's banking efficiency presents mixed results. Chen et al. (2005) and Hsu and Chang (2005) found that FHC banks are generally more efficient than non-FHC banks. Liu et al. (2006) also reported higher efficiency in FHC banks. However, Chiou (2009) observed no significant improvement in efficiency or productivity for FHC banks, except for pure technical efficiency. Chao et al. (2010) found that business diversification improves overall FHC performance, while Chen et al. (2010) reported better operational performance for FHC banks from 2004 to 2006. Liu and Hsu (2014) attributed stronger profitability in FHCs to benefits like business diversification and lower financial costs. Conversely, Kao et al. (2012) and Zhu et al. (2014) found no superior performance in FHC banks post-reform, with Zhu et al. (2014) concluding that FHC affiliation did not enhance profitability or marketability. Chao et al. (2018) used a convex meta-frontier approach and found that while FHC banks perform better in profitability, they lag behind non-FHC banks in marketability. Yu et al. (2021) indicated that FHC banks are less efficient in deposit and lending compared to non-FHC banks, though the results were not statistically significant.

To better understand bank operations, Seiford and Zhu (1999) introduced a two-stage production process model, focusing on profitability and marketability but lacking consideration of the linkage between these sub-processes. Färe and Grosskopf (2000) proposed a NDEA structure to decompose overall efficiency (OE) into multiple production stages, which was further developed by Sexton and Lewis (2003) to link sub-processes through intermediate products. Chen and Zhu (2004) extended this model, and Fukuyama and Weber (2010) applied a two-stage network model to Japanese banks. Premachandra et al. (2012) assessed performance by decomposing efficiency into operational and portfolio management. Nagaraju (2014) examined profitability and marketability efficiency in Indian banks from 2006 to 2010. Chiu et al. (2016) incorporated undesirable outputs in their analysis of various bank formats in Taiwan, while Rakshit (2021) used a two-stage model for Indian banks. Lin et al. (2022) employed a multi-stage network slacks-based measure model to evaluate Taiwanese FHCs, finding inefficiencies, particularly in profitability, during the global financial crisis.

2.3 Meta-Frontier Framework

Traditional DEA measures the efficiencies of decision-making units (DMUs) under a homogeneous frontier. However, the relative efficiencies may be incorrectly measured when the DMUs with different production technologies are referring to a homogeneous frontier (Huang, 2009; Huang et al., 2013; Chiu et al., 2013). In order to evaluate efficiencies with a non-homogeneous frontier, Hayami and Ruttan (1970) initially proposed some type of meta-production function. This meta-production function concept has been applied in several studies in the agricultural sector across country-level data (eg., Lau and Yotopoulos,1989, among others). O'Donnell et al. (2008) refined the methodology and finalized the framework for making efficiency comparisons across groups of firms using both stochastic and non-parametric meta-frontier approaches, and suggested that the metaset is convex when estimating the meta-frontier. Thereafter, the convex meta-frontier approach has been widely applied across several sectors such as agriculture (e.g., Latruffe et al., 2012), Taiwanese banking (e.g., Chiu et al., 2016; Chao et al., 2018), fisheries (Lee and Midani, 2015), hotels (Huang et al., 2013 , among others), schools (e.g., Thieme et al., 2013), and water utilities (e.g., De Witte and Marques, 2009).

In addition to convex meta-frontier approach for heterogeneity production possibility, Tone (1993) proposed a two-system model with a non-convex assumption to measure the efficiencies of DMUs with non-homogenous frontier. Huang (2009) applied the two-system model proposed by Tone (1993) to the Chen-Zhu two-stage model (Chen and Zhu. 2004) developing a non-homogeneous two-stage model to investigate two-stage operational efficiency of Taiwanese hotels. Recently, Kerstens et al. (2019) provided empirical evidence that the convexification strategy assuming a convex metaset generally leads to erroneous results. Jin et al. (2020) further provide statistical evidence for potential biases arising from the application of convexification strategies to the meta-frontier productivity indices. In the literature, regarding the application of non-convex meta-frontier model, O'Donnell et al. (2017) employed convex group-specific sets and non-convex metasets to measure changes in total factor productivity across a firm's multiple technologies. Yin et al. (2018) simultaneously incorporate a non-concave meta-frontier technique, undesirable outputs into a network slacks-based measure model to evaluate banking super efficiency. Yu et al. (2021) proposed a two system slacks-based measure of Dynamic DEA with a non-convex meta-frontier approach to assess the performance of FHC banks and non-FHC banks in Taiwan.

As mentioned earlier, the changes in the IFRS system in Taiwan do affect the performance assessment of the banking industry, but previous studies have ignored the significant differences between FHC and non-FHC banks in terms of profitability and marketability technologies. This study conducts the impact of IFRS introduction on the performance assessment of FHC and non-FHC banks in Taiwan without assuming the meta-frontier as convexity. It is important for banks' operations management and policy makers to understand how to improve the efficiency of banks under the IFRS system. The answers to the questions are important for banks' operation management and policy makers to set targets for improving banks' efficiency.

3. Methodology

3.1. NDEA Approach in Banks' Performance

DEA is a powerful method widely used to evaluate the performance of DMUs (Berger and Humphrey, 1997; Cook et al., 2005). DEA is commonly employed to measure relative banking efficiency among a set of homogeneous DMUs (Sherman and Zhu, 2006). The most prevalent DEA models include the Charnes-Cooper-Rhodes (CCR) model, introduced by Charnes et al. (1978), and the Banker-Charnes-Cooper (BCC) model, proposed by Banker et al. (1984).

However, traditional DEA models treat the DMU as a black box, providing limited insight into the detailed components of the bank's production process. To address this limitation, Färe and Grosskopf (2012) decomposed overall efficiency into distinct components. Seiford and Zhu (1999) further refined this approach by decomposing bank operations into two sub-processes: profitability and marketability. They argued that evaluating a bank's operational performance requires not only assessing profitability but also measuring the bank's ability to create market value for its stocks.

Seiford and Zhu's (1999) two-stage model, however, did not account for the relationship between these sub-processes. To address this, Sexton and Lewis (2003) extended the model by linking the two sub-processes through intermediate products. In their approach, the first stage involves the consumption of inputs to produce intermediate products, which are then used in the second stage to generate final outputs. Chen and Zhu (2004) further modified this model by incorporating the optimal use of intermediate products to assess marginal benefits and productivity based on the identified two-stage best practice frontier.

3.2. Two-System Non-Convex Frontier Approach

Apart from traditional DEA, which applies a homogeneous frontier to measure the efficiency of a DMU, Tone (1993) proposed the two-system DEA model, arguing that a DMU may exhibit different characteristic types. Tone (1993) posited that the production possibility set is non-convex, and the efficiency frontier encompasses several non-homogeneous production possibility sets. Building on the non-convex model with a non-homogeneous frontier first defined by O'Donnell et al. (2008), Huang (2009) applied Tone's two-system model to the Chen-Zhu two-stage model (Chen and Zhu, 2004), developing a non-homogeneous two-stage model to investigate the operational efficiency of Taiwanese hotels. Huang et al. (2013) further developed a non-convex meta-frontier model to explore the technology gaps among four operating types of Taiwan's international tourist hotels. Afsharian et al. (2018) proposed a new non-convex meta-frontier Malmquist index to evaluate productivity in the elevator and escalator industry. Kerstens et al. (2019) introduced a refined approach for nonparametric envelopment of non-convex metasets, illustrating potential errors associated with established methods. Yu et al. (2019) integrated the non-convex metafrontier and undesirable outputs into an NDEA model, enabling the measurement of efficiency using dynamic network slacks-based measures. Jin et al. (2020) suggested that convexification strategies yield biased estimators.

In the context of Taiwanese commercial banks, the two systems are classified by their organizational structures: FHC banks, which are subsidiaries of FHCs, and non-

FHC banks, which operate independently. Since the establishment of the FHC Act in Taiwan, FHCs, which own two or more subsidiaries, have provided FHC banks with resources that enable diversified activities, including cross-selling, which can reduce costs, enhance banking profits, and create synergistic benefits.

Given these distinctions, this study aims to use non-convex meta-frontier functions to evaluate operational efficiency across the two systems of Taiwanese banks.

We start with the definition of the two-stage network production technology as given in Chen and Zhu (2004). We denote input as $\mathrm{x} = (x_1,...,x_N) \in R_+^N$, intermediate products flow out from the first stage (profitability) and into stage 2 (marketability) as $\mathrm{z}^{1\to 2} = (\mathrm{z}_1^{1\to 2},...,\mathrm{z}_S^{1\to 2}) \in R_+^S$ and outputs by $\mathrm{y} = (y_1,...,y_J) \in R_+^J$. The technology set S of the first and second stages are denoted respectively by:

$$T^1 = \left\{ \left(\mathrm{x}, \mathrm{z}^{1\to 2}\right) : \mathrm{x}\ can\ produce\ \mathrm{z}^{1\to 2} \right\}$$

$$T^2 = \left\{ \left(\mathrm{z}^{1\to 2}, \mathrm{y}\right) : \mathrm{z}^{1\to 2}\ can\ produce\ \mathrm{y} \right\}$$

The linking activities $\mathrm{z}^{1\to 2} = (\mathrm{z}_1^{1\to 2},...,\mathrm{z}_S^{1\to 2}) \in R_+^S$ describe the network production feature, namely that the inputs $\mathrm{x} = (x_1,...,x_N) \in R_+^N$ are used to produce intermediate products which flow into the second stage to produce outputs by $\mathrm{y} = (y_1,...,y_J) \in R_+^J$. The network production technology can be denoted by:

$$T = \left\{ \left(\mathrm{x}, \mathrm{z}^{1\to 2}, \mathrm{y}\right) : \mathrm{x}\ can\ produce\ \mathrm{y}\ through\ production\ of\ \mathrm{z}^{1\to 2} \right\}$$

The two-stage NDEA technology structure (Fig. 1) that treats intermediate products in the free link forms by imposing two sets of inequality constraints can be set up as:

$$T = \left\{ \begin{array}{l} \left(\mathrm{x}, \mathrm{z}^{1\to 2}, \mathrm{y}\right) : \sum\limits_{k\in ALL} x_{ik}\lambda_k \le x_i\ (\forall i),\ \sum\limits_{k\in ALL} z_{sk}^{1\to 2}\lambda_k \ge z_s^{1\to 2}\ (\forall s),\ \sum\limits_{k\in ALL} z_{sk}^{1\to 2}\mu_k \le z_s^{1\to 2}\ (\forall s), \\ \sum\limits_{k\in ALL} y_{rk}\mu_k \ge y_r\ (\forall r),\ \lambda_k \ge 0,\ \mu_k \ge 0,\ (\forall k) \end{array} \right\}$$

The λ_k and μ_k indicate the intensity variables of the *k*th firm in constructing the efficient frontier of stage 1 and 2, respectively, for a specific point $\left(\mathrm{x}, \mathrm{z}^{1\to 2}, \mathrm{y}\right)$ in the production set.

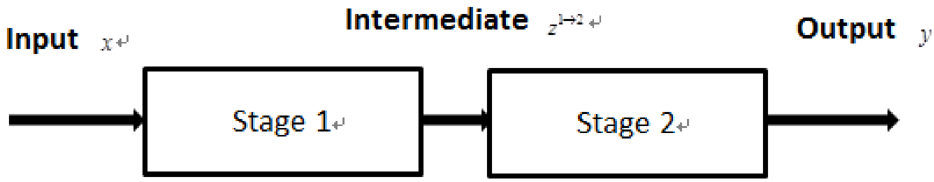

Fig.1. Two-stage NDEA technology structure

In this study, we integrate the two-system concept into a directional distance function NDEA model (details provided in Appendix B). We categorize banks into two systems based on whether they are subsidiaries of FHCs or operate independently. This approach evaluates the profitability and marketability efficiencies (PE and ME) of Taiwan's commercial banks following IFRS adoption. To maintain clarity, we introduce the specification of the two-system NDEA model program, where both stages are divided into System A (FHC banks) and System B (non-FHC banks), as outlined below:

$$\underset{\theta_1,\theta_2,\lambda_i,\mu_i,\tilde{z},p_A^1,p_B^1,p_A^2,p_B^2}{Max} \quad w_1 \times \theta_1 + w_2 \times \theta_2 \text{......} (1)$$

s.t.

$$\sum_{k \in A} x_{ik}\lambda_k + \sum_{k \in B} x_{ik}\lambda_k \leq (1-\theta_1)x_{ik'},\ i = 1,\ldots,N \text{......} (2)$$

$$\sum_{k \in A} z_{sk}^{1\to2}\lambda_k + \sum_{k \in B} z_{sk}^{1\to2}\lambda_k \geq z_{sk'}^{1\to2},\ s = 1,\ldots,S \text{......} (3)$$

$$\sum_{k \in A} z_{sk}^{1\to2}\mu_k + \sum_{k \in B} z_{sk}^{1\to2}\mu_k \leq z_{sk'}^{1\to2},\ s = 1,\ldots,S \text{......} (4)$$

$$\sum_{k \in A} y_{rk}\mu_k + \sum_{k \in B} y_{rk}\mu_k \geq (1+\theta_2)y_{rk'},\ r = 1,\ldots,R \text{......} (5)$$

$$\sum_{k \in A} \lambda_k = p_A^1,\ \sum_{k \in B} \lambda_k = p_B^1 \text{......} (6)$$

$$\sum_{k \in A} \mu_k = p_A^2,\ \sum_{k \in B} \mu_k = p_B^2 \text{......} (7)$$

$$p_A^1 + p_B^1 = 1,\ p_A^1, p_B^1 = 0 \ or\ 1 \text{......} (8)$$

$$p_A^2 + p_B^2 = 1,\ p_A^2, p_B^2 = 0 \ or\ 1 \text{......} (9)$$

$$\lambda_k \geq 0,\ \mu_k \geq 0,\ k = 1,\ldots,K \text{......} (10)$$

$$\theta_1 \leq 1,\ \theta_2 \geq 0 \text{......} (11)$$

where θ_1 is a scalar taking a value between zero and one, which addresses the rate of the reduction of input quantities while producing a given level of intermediate quantities, and θ_2 addresses the rate of the expansion of output quantities while using a given level of intermediate quantities. λ_k represents the intensity variable of stage 1 in system A and system B if $k \in A$ and $k \in B$, respectively. μ_k represents the intensity variables of stage 2 in system A and system B if $k \in A$ and $k \in B$, respectively. if $p_A^1 = 1,\ p_B^1 = 0$ and $p_A^2 = 1,\ p_B^2 = 0$ (Appendix B, case I); $p_A^1 = 1,\ p_B^1 = 0$ and $p_A^2 = 0,\ p_B^2 = 1$ (Appendix B, case II); $p_A^1 = 0,\ p_B^1 = 1$ and $p_A^2 = 1,\ p_B^2 = 0$ (Appendix B, case III) and $p_A^1 = 0,\ p_B^1 = 1$ and $p_A^2 = 0,\ p_B^2 = 1$ (Appendix B, case IV)

After optimal solution $\left(\theta_1^*, \theta_2^*\right)$ is obtained, we define the stage 1 efficiency indicator estimated by the two-system non-convex NDEA model for as $1-\theta_1^*$, the stage 2 efficiency indicator as $1/(1+\theta_2^*)$. As profitability stage and marketability stage may not be considered equally important, their relative importance can be modeled by means of weights, w_1 and w_2 associated with θ_1 and θ_2, respectively, where $w_1 + w_2 = 1$, and w_1 and w_2 are the relative weights of profitability and marketability activities which are determined according to their importance. We define the value of $w_1 \times (1-\theta_1^*) + w_2 \times \left[1/(1+\theta_2^*)\right]$ which can be considered a measure of OE indicator $NC-OE$.[b]

Studies such as those by Luo (2003), Lo and Lu (2009), Liu (2011), Zhu et al. (2014), and Chao et al. (2015) that investigated the efficiency of Taiwan's banks all employed a two-stage efficiency framework, distinguishing between profitability and marketability. In these studies, equal weights were assigned to both stages to measure overall efficiency. Since both profitability and marketability are equally critical to the productivity efficiency of banks, this study follows the precedent set by the aforementioned literature and assigns equal weights to measure the overall efficiency of Taiwanese banks.

4. Empirical Results Analysis and Implications

4.1 Data and Specification of Inputs and Outputs

This study aims to evaluate the operational efficiencies of Taiwanese commercial banks over the period from 2013 to 2022, particularly in the context of the implementation of International Financial Reporting Standards starting in 2013. To achieve this, we utilized a panel dataset comprising 18 Taiwanese banks, selected based on the availability of key financial indicators such as the price-to-earnings (P/E) and price-to-book (P/B) ratios. The data were sourced from the Annual Reports of listed commercial banks published by the Taiwan Stock Exchange Corporation. Among these eighteen banks, ten are part of FHC, while the remaining eight are independent, as detailed in Appendix C.

In the two-stage NDEA model framework introduced by Seiford and Zhu (1999), which models bank performance in terms of profitability and marketability efficiencies, the inputs to the profitability process, the final outputs of the marketability process, and the intermediate products linking the two sub-processes are significantly influenced by accounting items and figures, based on new definitions and accounting methods introduced by IFRS. The accounting items affected by IFRS, as summarized by Chao et al. (2015), are detailed in Table 1.

Seiford and Zhu (1999) utilized employee numbers, assets, and stockholders' equity as inputs in the first stage to generate revenues and profits (outputs). In the second stage, revenues and profits are used as inputs to produce market value, total return to investors, and earnings per share (outputs). Following this approach, studies such as Zhu (2000), Luo (2003), Lo and Lu (2006), and Rakshit (2021) also employed employees, assets,

[b] For the purpose of comparison, under the assumption of a convex meta-frontier, as estimated by Model A in Appendix A, the PE, ME, and OE measures are respectively denoted as $C-PE$, $C-ME$, and $C-OE$.

and stockholders' equity as inputs, and revenue and profits as outputs to measure profitability efficiency. Nagaraju (2014) used assets, equity, operating expenses, and employees as inputs in the profitability stage, and revenue, profit margin, equity, operating expenses, and employees as inputs in the profitability stage, with revenue, profit margin, return on assets, and return on equity as outputs to measure profitability efficiency. Chao et al. (2018) considered operating expenses, depreciation and amortization expenses, and interest revenue and non-interest revenue as outputs (intermediates) to assess profitability efficiency.

These studies primarily emphasize the relationship between inputs and outputs in measuring profitability efficiency in bank operations. Since assets and stockholders' equity are stock concepts that cannot be proportionally reduced in the short term like the variable input 'number of employees', we adopt the input items proposed by Chao et al. (2018) for measuring profitability efficiency, namely operating expenses and depreciation expenses. These inputs cover labor costs and asset depreciation, among other operating expenses. We exclude profits as an output of the profitability process because profits = total revenue − total cost, which would lead to double-counting of inputs (Cooper et al., 2007). Given that NDEA models require precise input and output data, we follow the variables defined by Chao et al. (2018), who utilized a network structure model to investigate the Taiwanese banking sector following the first-time adoption of IFRS financial information from 2013 to 2022.

Table 1. IFRS effects on income statement accounting items

Item	Effect on account
IFRS1: First-time adoption of International Financial Reporting Standards	1. Asset values (depreciation expenses for fixed assets and amortization expenses for intangible assets 2. Retained earnings (1/1)
IFRIC13: Customer Royalty Program	1. Commission income 2. Deferred revenue 3. Administrative expenses
IAS19: Employee Benefits	1. Interest expense 2. Staff costs – employee benefit costs 3. Pension costs
IAS21: The Effects of Changes in Foreign Exchange Rates	1. Non-interest revenue
IAS39: Financial Instruments : Recognition and Measurement	1. Gain or loss on investment in financial assets 2. Investments- financial assets

Source: Chao et al. (2015)

Following Chao et al. (2018), in the first stage (profitability stage), we choose operating expenses (x_1) including interest expenses, staff expenses, and other business and administrative expenses, and depreciation expenses for fixed assets and amortization expenses for intangible assets (x_2) as input variables, and choose interest revenues ($z_1^{1\to2}$) defined as interest from lending and non-interest revenues ($z_2^{1\to2}$)

including (a) investment-related net revenues, (b) unrealized holding gains or losses from fair value changes in available for-sale financial assets, (c) interest revenues from held-to-maturity debt financial assets, and (d) investment gains and losses from long-term investment. It also includes commission fees and other income as intermediate output variables. This process assesses how effectively a bank generates revenues (interest and non-interest revenues) from its operations. It involves analyzing metrics such as operating expenses, depreciation expenses and amortization expenses. Profitability efficiency measures the bank's ability to generate earnings relative to its expenses. In the second stage (marketability stage), interest revenues ($z_1^{1\to2}$) and non-interest revenues ($z_2^{1\to2}$) are treated as input variables, and stock price (31 December, 2012) to earnings per share ratio (P/E, y_1) and stock price (31 December, 2012) to book value of stockholders' equity ratio (P/B, y_2) are chosen as output variables. This process focuses on how effectively a bank can convert its revenues (both interest and non-interest revenues) into market value (measured by P/E and P/B ratios). Marketability efficiency assesses how well a bank can transform its earnings or revenues into stock value. In this context, it evaluates the bank's ability to use its income or revenues to enhance the value of its shares in the stock market. This efficiency is crucial as it determines the attractiveness of the bank's stocks to investors and impacts the bank's overall market performance. Essentially, it gauges the bank's capability to generate investor interest and confidence through its financial performance.

In summary, the NDEA model's profitability efficiency measures the bank's ability to convert expenses into revenues, marketability efficiency evaluates its effectiveness in translating revenues into market value, and overall efficiency assesses how well the bank uses its expenses to generate investor interest and confidence. Together, these three components provide a comprehensive view of a bank's financial performance and operational effectiveness.

As illustrated in Fig. 2, the profitability efficiency model assesses a bank's ability to generate revenues using two inputs: operating expenses and depreciation and amortization expenses. It produces two intermediate outputs: interest revenue and non-interest revenue. These intermediate outputs from the profitability stage then serve as inputs for the marketability stage, which produces two outputs: P/E and P/B ratios. These ratios measure the marketability efficiency of the bank's attractiveness in the stock marke

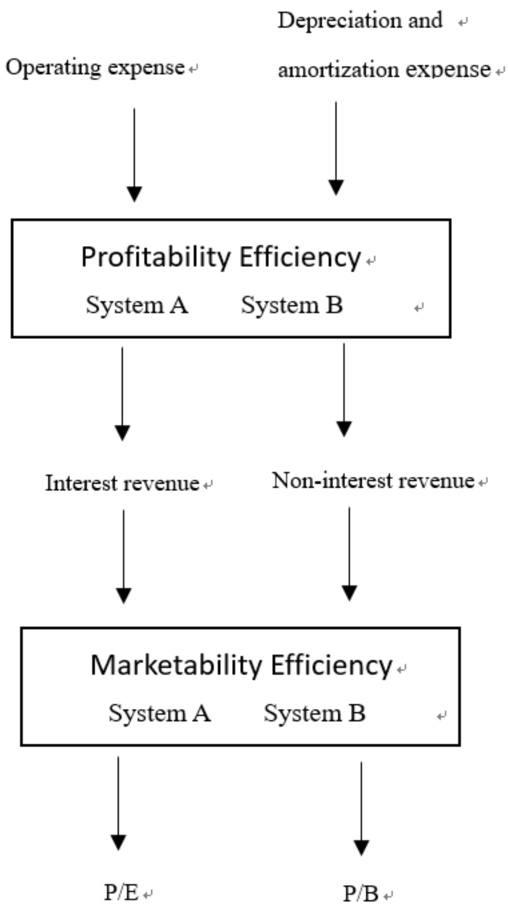

Fig. 2. Two-system NDEA efficiencies.

Table 2 summarizes the input, intermediate, and output variables for systems A (FHC banks) and B (non-FHC banks) from financial reports under IFRS, along with descriptive statistics for the period from 2013 to 2022. As shown in Table 2, the average values for all variables, except for P/E and P/B ratios, are consistently higher for FHC banks compared to non-FHC banks. This indicates that Taiwanese FHC banks generally operate on a larger scale and have a broader business scope than non-FHC banks (Yu et al., 2021). The higher average values suggest that FHC banks may outperform non-FHC banks in terms of financial service assets and operational scale during the period studied.

Table 2. Descriptive statistics for inputs, intermediates and outputs from 2013 to 2022

	FHC				Non-FHC			
	Min.	Max.	Mean	S.D.	Min.	Max.	Mean	S.D.
2013								
operating expenses (thousands NT$)	10555.5	44583.6	26836	9737.3	2607.5	23503.5	8418.8	6636.2
depreciation expenses (thousands NT$)	330.5	1901.6	903.8	430	78.6	1538.8	401.9	505.9
interest revenues (thousands NT$)	12393.2	47864.1	29996.1	10447.9	3989.9	26636.8	9507.7	7223.1
non-interest revenues (thousands NT$)	4092.6	27995.2	12045.5	6537.9	921.1	9498.3	3733.2	2692.1
P/E (ratio)	0.6	1.9	1	0.4	0.6	1.1	1	0.2
P/B (ratio)	4.3	15.5	9.9	3.5	2.9	14.2	9.1	3.7
2014								
operating expenses (thousands NT$)	26.6	1066351.9	132530.4	328439.2	2935.8	26690.2	11377.2	8383
depreciation expenses (thousands NT$)	408.9	1591	868.6	351.4	36.9	714.5	244.5	220
interest revenues (thousands NT$)	15409.9	50598.4	34116.5	10750.3	4613.7	31862.5	13543.1	9736.2
non-interest revenues (thousands NT$)	5356.8	49268.8	17253.5	12330.3	897.9	5997.8	3475.4	1587.6
P/E (ratio)	0.6	9.7	2.2	2.8	0.6	12.5	2.5	4
P/B (ratio)	5	24.7	11.5	6.7	7.6	13.2	9.4	2.3
2015								
operating expenses (thousands NT$)	12925.1	54036.4	31955.7	11068.8	2964.2	26824.6	11552.4	8404.9
depreciation expenses (thousands NT$)	435.7	1979.3	985.9	417.6	46.7	701.3	249.9	209.4
interest revenues (thousands NT$)	14743.4	50960.7	32218.4	12054.2	4780.4	32991.5	13867.4	10066.4
non-interest revenues (thousands NT$)	4939	49632.3	16562.7	12796.8	782.7	8503.5	3653.5	2456.9
P/E (ratio)	0.5	2.7	1	0.7	0.6	1	0.8	0.2
P/B (ratio)	4.5	24.9	10.1	6.3	7.5	11.4	9	1.6
2016								
operating expenses (thousands NT$)	12049.4	51103.6	30871.5	10653.2	3069.5	25932.3	11070.4	8105.3
depreciation expenses (thousands NT$)	436.4	2157	1043.5	452.1	51.1	717.9	266.2	213.5
interest revenues (thousands NT$)	15278.6	50110.1	33637.4	10759.1	4401.7	32589.5	13214.3	9914.2
non-interest revenues (thousands NT$)	3974.1	39616.8	16433.5	10291.3	787.6	9281.7	3900.4	2620.6
P/E (ratio)	0.6	3.1	1.1	0.8	0.6	1.1	0.8	0.2
P/B (ratio)	5.9	37.5	13.7	9.5	6.8	23.1	11.2	5.2

2017								
operating expenses (thousands NT$)	8130.7	55054.3	31846	12540.4	1441.6	27048.5	10902.3	8759
depreciation expenses (thousands NT$)	451.4	2225.5	1100	487.7	51	718.8	279.4	215.2
interest revenues (thousands NT$)	15516.3	50739.4	35924.6	11320.5	4388.7	34602.9	13477.2	10611.2
non-interest revenues (thousands NT$)	4154.7	44620.3	17458.6	11662.5	735.8	8139.9	3942.9	2242.9
P/E (ratio)	0.7	3	1.2	0.8	0.5	1.2	0.8	0.2
P/B (ratio)	9.1	32.1	13.6	7.4	7.6	19.6	11.2	3.8
2018								
operating expenses (thousands NT$)	13016.6	60713.4	37281.1	12843.9	3514.4	30572.7	12475.3	9642.5
depreciation expenses (thousands NT$)	469.6	2412.9	1204.2	555.3	49.7	714.1	284.2	223.2
interest revenues (thousands NT$)	17011.9	58744.2	40790.1	13124.6	4961.5	38335.8	14922.8	11927.9
non-interest revenues (thousands NT$)	4195.5	42418	18968.1	11112.4	868	9870.6	4077.5	2835.4
P/E (ratio)	0.6	2.7	1.1	0.7	0.5	1.1	0.8	0.2
P/B (ratio)	6.8	27.1	12.3	6.3	8.6	19.8	11.3	3.8
2019								
operating expenses (thousands NT$)	13777.6	66711.9	40728.1	13675	3802.9	30775.1	12907	9680.8
depreciation expenses (thousands NT$)	1030.1	4423.4	2160.9	983.8	124.8	1394.4	605.9	431.4
interest revenues (thousands NT$)	18024.1	65422.5	43910.1	14001.9	5215.8	38289	15332.8	11983.8
non-interest revenues (thousands NT$)	4791.7	46934.9	21340.7	12082.9	955.5	9641	4651.8	2638.2
P/E (ratio)	0.7	2.6	1.2	0.6	0.6	8.4	1.8	2.7
P/B (ratio)	8.3	25.9	13.3	5.2	10.3	19.6	13	3
2020								
operating expenses (thousands NT$)	13043.8	54894.4	33935.3	10966	2927.7	24906.9	10855.6	7930.9
depreciation expenses (thousands NT$)	1046.5	4721.8	2312.2	1060.8	130.9	1348.9	603.6	421.1
interest revenues (thousands NT$)	16314.3	57393.7	37998.2	11813.7	4246.1	28936.8	12935.4	9148
non-interest revenues (thousands NT$)	5608.9	40282.6	19364.9	10493.3	1120.2	8472	4168.8	2249.8
P/E (ratio)	0.6	2.6	1.1	0.6	0.6	1.1	0.8	0.2
P/B (ratio)	6.9	29.6	14.1	6.6	7.9	25.1	14.4	5.1
2021								
operating expenses (thousands NT$)	12416	55880.7	30866	11353.6	2601.6	21822.5	9648.9	7067.2
depreciation expenses (thousands NT$)	1059.3	4700.4	2380.7	1055.3	18.2	10329.5	1757.8	3489.2

interest revenues (thousands NT$)	16552.8	55431.4	36422.2	11217.3	3902.2	26677.3	12268	8595.4
non-interest revenues (thousands NT$)	5841.3	44534.2	19092.6	10963.7	1222.9	8303	4466.7	2251.8
P/E (ratio)	0.8	4.2	1.5	1.1	0.7	1	0.8	0.1
P/B (ratio)	8	49.9	18.1	12.4	8.1	20.2	13.5	3.6
2022								
operating expenses (thousands NT$)	16095.3	69649.6	43744.9	13858.5	4040.3	32512.5	13262	10510
depreciation expenses (thousands NT$)	1084.5	4884.3	2499.4	1098.6	130.1	1497.4	651.2	497.2
interest revenues (thousands NT$)	20117	81092.1	50202.4	19337	4713.5	40723.3	16818.8	13123
non-interest revenues (thousands NT$)	5150	43015.9	18973.2	10492.3	-556.7	9560.8	3996.6	3462.9
P/E (ratio)	0.8	6.9	1.9	1.9	0.8	1.1	0.9	0.1
P/B (ratio)	6.2	32	14.3	7.1	10.3	27.3	16.1	5.6

Note: NT$ represents New Taiwan Dollar.

4.2 Efficiency Analysis

Taiwan officially adopted IFRS in 2013. To understand the impact of IFRS adoption on financial statements, the government required that the financial statements for the year before the official adoption (2012) disclose data according to both the old and new standards. Therefore, financial statement data prepared under both standards for 2012 is available. Before commencing the analysis, it is crucial to determine whether the use of different accounting standards affects the performance evaluation results. This study first examined the results obtained from evaluating two sets of data. The Wilcoxon signed-rank test, a non-parametric hypothesis testing method, was used to compare paired datasets to assess whether they originate from the same distribution. Specifically, the Wilcoxon signed-rank test was applied to determine if there is a significant difference in the results when using data extracted from financial statements in 2012. The results of this test are presented in Appendix D. Upon confirming that different accounting standards impact the performance evaluation results, the study proceeds by analyzing the results of the convex and non-convex meta-frontier in the next subsection, followed by an examination of the non-convex two-system NDEA model in Section 4.2.2.

4.2.1 Wilcoxon Signed-Rank Test for the Difference Between Non-convex and Convex models

As previously mentioned, Chao et al. (2018) employed a convex meta-frontier approach to evaluate the efficiency of two groups of Taiwanese commercial banks. However, this study aims to enhance the efficiency evaluation of these banks under IFRS by using a non-homogeneous frontier (Kerstens et al., 2019). Thus, a non-convex meta-frontier model is applied to assess the two-stage efficiencies of the two bank groups. It is essential to determine whether the differences observed between the non-convex and convex meta-frontier models are statistically significant. To address this, the study revisits the results of Chao et al. (2018) and presents new findings. The Wilcoxon signed-rank test is then employed to test the statistical significance of these differences.

The results from the Wilcoxon signed-rank test are presented in Table 3. If the p-value is less than or equal to 0.1, the null hypothesis is rejected, indicating that the samples are significantly different. The findings in Table 3 reveal that while some annual tests show no significant differences, most annual PE and ME values exhibit significant variations due to the convexity of the meta-frontier adopted.

Table 3. Wilcoxon Signed-Rank test for the difference between non-convex and convex models (2013-2022)

Period	$NC-PE_A$ vs. $C-PE_A$	$NC-PE_B$ vs. $C-PE_B$	$NC-ME_A$ vs. $C-ME_A$	$NC-ME_B$ vs. $C-ME_B$
2013	0.047**	0.028**	0.028**	0.028**
2014	0.086	0.237	0.043**	0.063*
2015	0.779	0.144	0.043**	0.028**
2016	0.374	1.000	0.066*	0.285
2017	0.011**	0.916	0.138	0.027**
2018	0.074*	0.028**	0.109	0.043**
2019	0.047**	0.109	0.169	0.317
2020	0.866	0.028**	0.043**	0.491
2021	0.933	0.317	0.027**	0.317
2022	0.005***	0.144	0.715	0.028**

Note: 1.*** significance at the 1% level, **significance at the 5% level, *significance at the 10% level.
2. The subscripts of PE and ME respectively represent systems A (FHC banks) and B (non-FHC banks); while C and NC represent convex and non-convex meta-frontiers, respectively.

4.2.2 Empirical Results

After establishing a significant difference in the efficiency estimation between convex and non-convex meta-frontiers, further testing was conducted within the non-convex meta-frontier to determine whether there was a significant difference in the efficiency of the two stages. The Mann-Whitney *U* test is broadly used to determine whether two independent samples (in this case, FHC and non-FHC banks) are from the same distribution. Therefore, we use the Mann-Whitney *U* test to compare the differences between annual $NC-OE_A$ and $NC-OE_B$, $NC-PE_A$ and. $NC-PE_B$, $NC-ME_A$ and $NC-ME_B$ from 2013 to 2022. As shown in Table 4, most of the results of the Mann-Whitney *U* test for annual $NC-ME$ between the two systems are significant, except for the years 2014 and 2019. As regards the differences in the annual $NC-PE$ between FHC and non-FHC banks, the test results show that there are significant differences between the two systems of banks in 2015, 2016, 2018, and 2020. On the whole, the Mann-Whitney *U* test results shown in Table 4 indicate that there are significant differences between $NC-PE$ and $NC-ME$ of FHC and non-FHC banks, but not in $NC-OE$ over the period 2013–2022 (i.e., since IFRS adoption).

Table 4. Mann-Whitney U test between banking efficiency of two-system banks (2013-2022)

	P-Value									
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
$NC-OE_A$ vs. $NC-OE_B$	0.476	0.859	0.984	0.984	0.155	0.929	0.424	0.756	0.213	0.477
$NC-PE_A$ vs. $NC-PE_B$	0.789*	0.243	0.008***	0.070*	0.307	0.075*	0.398	0.048**	0.178	0.656
$NC-ME_A$ vs. $NC-ME_B$	0.005***	0.053	0.004***	0.010**	0.026**	0.007***	0.141	0.003***	0.004***	0.074*

*** significance at the 1% level, **significance at the 5% level, *significance at the 10% level.

Table 5 provides full details of the average OE (AOE), average PE (APE) and average ME (AME) for all banks in the sample period from 2013 to 2022. System A refers to those banks that are FHC banks, whereas System B refers to non-FHC banks. The empirical results are presented in Table 5 and, which shows the annual OE ($NC-AOE_A$ and $NC-AOE_B$), annual PE ($NC-APE_A$ and $NC-APE_B$), and annual ME ($NC-AME_A$ and $NC-AME_B$) scores of systems A and B for the period 2013–2022.

In Table 5, the empirical results are presented as the average score and ranking over ten observed time periods. Firstly, concerning the two-stage efficiency of the overall banking sector, the mean of AOE is 0.6817, revealing that banks' average efficiency still has room for improvement (of 31.83%). In addition, the results show that the average score of $NC-APE_A$ (0.7980) for FHC banks is higher than that of $NC-APE_B$ (0.5856) for non-FHC banks. As regards AME, the average score of $NC-AME_B$ (0.8229) for non-FHC banks is higher than $NC-AME_A$ (0.5343) for FHC banks. In addition, it is worth noting that the average score of $NC-AOE_B$ for non-FHC banks (0.7112) is higher than $NC-AOE_A$ for FHC banks (0.6581). The results indicate that non-FHC banks outperform FHC banks in terms of AOE and AME. Conversely, FHC banks show superior performance in APE. Regarding the rankings of average scores for AOE, APE, and AME, FHC bank A5 ranks 1st, and non-FHC bank B1 ranks 2nd among all sample banks. Despite belonging to different groups, these banks operate more efficiently than other banks in their respective categories and are the most efficient within their groups.

For AOE, among the top five banks, three are non-FHC banks (B1 = 2, B3 = 4, B7 = 3), and two are FHC banks (A5 = 1, A6 = 5). Conversely, among the bottom five banks, three are non-FHC banks (B4 = 14, B5 = 15, B8 = 18) and two are FHC banks (A1 = 18, A7 = 16). Additionally, some FHC banks rank significantly better in APE than in AME (e.g., A2, A3, A9, A10), whereas certain non-FHC banks show better rankings in AME than in APE (e.g., B2, B3, B4, B5, B8).

Table 5. Two-system NDEA average efficiencies from 2013 to 2022

System A	$NC-AOE_A$	Ranking	$NC-APE_A$	Ranking	$NC-AME_A$	Ranking
A1	0.4414	18	0.5475	14	0.3557	18
A2	0.6063	13	0.8860	3	0.3781	17
A3	0.6633	7	0.8417	5	0.5197	11
A4	0.6359	8	0.7994	8	0.4464	15
A5	0.9906	1	0.981	1	0.9988	1
A6	0.7663	5	0.8001	7	0.7442	9
A7	0.5878	16	0.7323	12	0.4066	16
A8	0.6325	9	0.7881	10	0.5178	12
A9	0.6273	11	0.8088	6	0.4818	13
A10	0.6298	10	0.7952	9	0.4870	14
Mean	0.6581		0.7980		0.5343	
Max	0.9906		0.9810		0.9988	
Min	0.4414		0.5475		0.3557	
System B	$NC-AOE_B$	**Ranking**	$NC-APE_B$	**Ranking**	$NC-AME_B$	**Ranking**
B1	0.9629	2	0.9352	2	0.9905	2
B2	0.6167	12	0.4049	16	0.7992	5
B3	0.7821	4	0.6646	13	0.8948	4
B4	0.5963	14	0.4169	15	0.7448	8
B5	0.5902	15	0.4039	17	0.7671	7
B6	0.7209	6	0.7675	11	0.7168	10
B7	0.9125	3	0.8709	4	0.9234	3
B8	0.5082	17	0.2212	18	0.7469	6
Mean	0.7112		0.5856		0.8229	
Max	0.9629		0.9352		0.9905	
Min	0.5082		0.2212		0.7168	
Overall	0.6817		0.7036		0.6622	

This study also computes the annual efficiency scores of FHC and non-FHC banks for each year as well as the trends in efficiency changes over the period 2013–2022 (i.e., since IFRS adoption). As regards $NC-AOE$ (shown in Fig. 3), non-FHC banks and FHC banks exhibit the same level of efficiency in years 2014, 2016 and 2018, while in the other years, non-FHC banks are superior to FHC banks. In addition, Fig. 3 also shows that a large gap between FHC and non-FHC banks exists after 2018 and that both systems of banks are in recession in 2021–2022. Furthermore, as shown in Fig. 4, FHC banks' $NC-APE$ is very close to that of non-FHC banks in 2013, but then in the other years is higher than that of non-FHC banks till 2022. It is worth noting that both systems of banks have the same $NC-APE$ in 2022. Fig. 5 illustrates that non-FHC banks' ME annually is higher than in the case of FHC banks during the period 2013–2022. Moreover, it also shows that the trend in $NC-AME$ changes for non-FHC banks is declining, but in the case of FHC banks, the ME is increasing from 2021 to 2022.

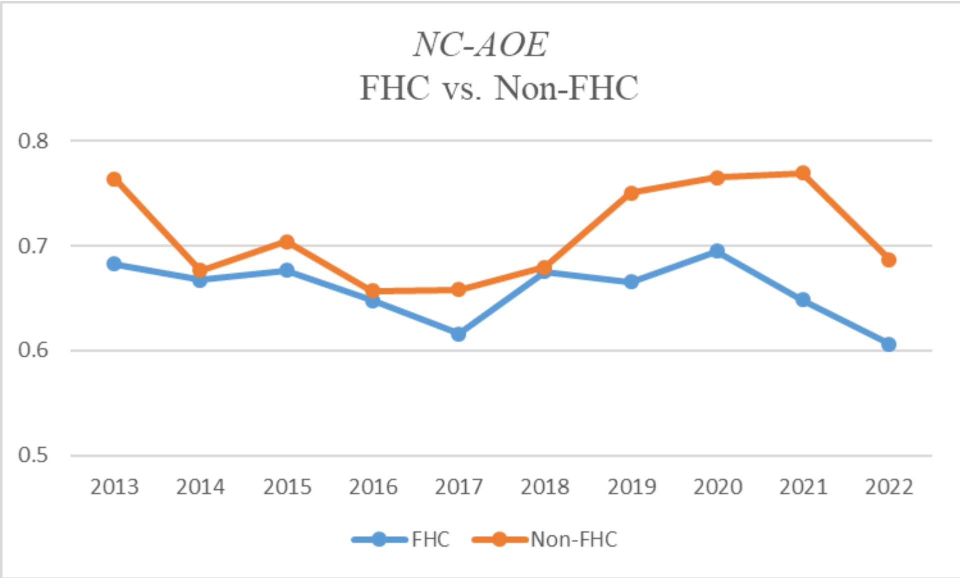

Fig. 3. Period $NC-AOE$ between FHC and non-FHC

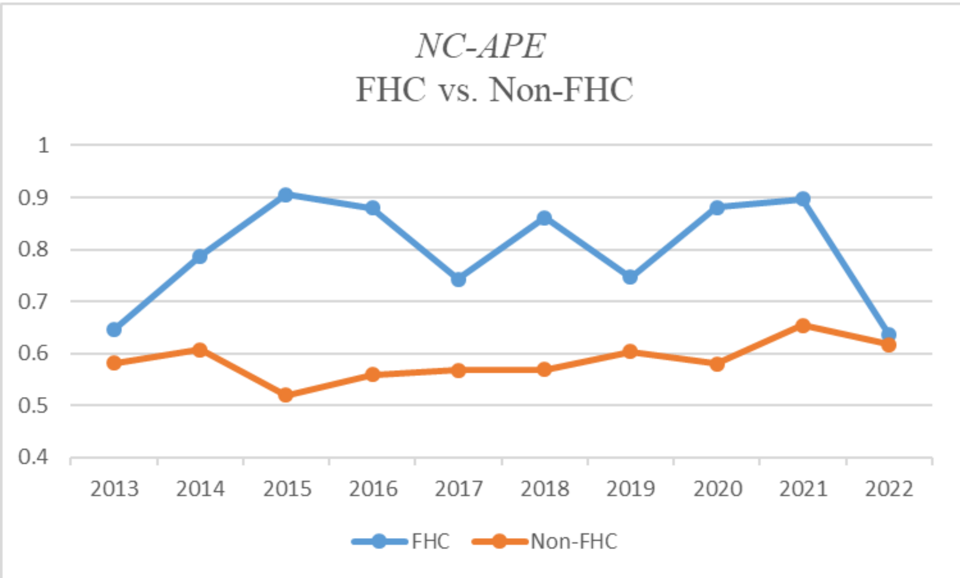

Fig. 4. Period $NC-APE$ between FHC and non-FHC banks

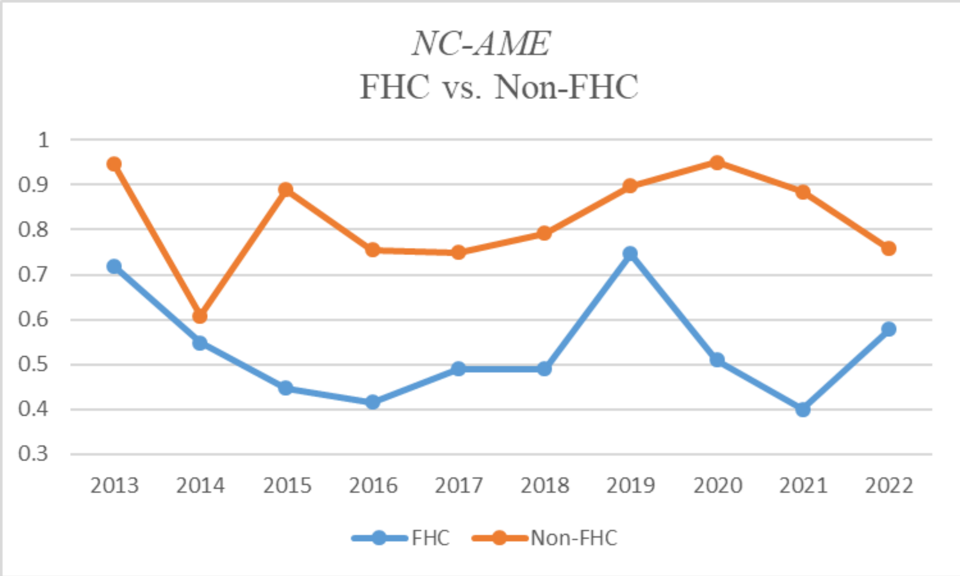

Fig 5. Period $NC-AME$ between FHC and non-FHC banks

4.3 Discussions and Implications

4.3.1 Discussions

Table 5 reveals that Taiwanese FHC banks exhibit greater PE compared to non-FHC banks. This suggests that, following IFRS adoption, FHC banks benefit from cross-selling synergies within their diversified financial subsidiaries. This finding supports previous research, including Chen et al. (2005), Hsu and Chang (2005), Liu et al. (2006), Chao et al. (2010), Chen et al. (2010), Liu and Hsu (2014), and Chao et al. (2018), all of which concluded that banking diversification can enhance operational efficiency.

However, Table 5 also shows that FHC banks lag behind non-FHC banks in converting revenues into market value. Seiford and Zhu (1999) suggested that larger banks might experience a negative effect on marketability, a view supported by Luo (2003), who found that larger banks have lower marketability efficiency. Chao et al. (2018) confirmed that while FHC banks exhibit superior profitability efficiency compared to non-FHC banks, they fall short in marketability efficiency. Rakshit (2021) similarly observed that large banks in India excel in profitability but smaller banks outperform in marketability. The Taiwan Banking Bureau reports that FHC banks generally have larger asset scales than non-FHC banks, which aligns with the findings of Seiford and Zhu (1999), Luo (2003), Chao et al. (2018), and Rakshit (2021). This suggests that non-FHC banks are more effective at using their profits to achieve higher market value.

Furthermore, these findings highlight the issue of conglomerate discount. Recent literature has largely criticized corporate diversification, with evidence showing that multi-division firms often trade at a discount compared to single-segment firms. Berger and Ofek (1995) found that conglomerates typically exhibit a negative excess value of 10 −15% on average. Laeven and Levine (2007) also observed that the market value of financial conglomerates is lower than if the same activities were conducted by specialized financial intermediaries. This discount may be attributed to agency problems, divisional rent-seeking, or top management's empire-building tendencies (Jensen, 1986; Rajan et al., 2000; Scharfstein and Stein, 2000).

4.3.2 Implications

Table 5 highlights that the mean value for APE exceeds the mean value for AME among listed banks in Taiwan. This suggests that the overall inefficiency of banks is more significantly impacted by inefficiencies in the marketability process compared to the profitability process.

When comparing the two-stage efficiency scores for FHC and non-FHC banks, the results indicate that FHC banks could potentially achieve higher average APE scores through mergers and acquisitions compared to non-FHC banks. Non-FHC banks should consider expanding their business scope to compete with FHC banks, which benefit from diversified revenues and reduced operational costs. Alternatively, non-FHC banks might focus on increasing and encouraging innovation to improve their PE.

Moreover, since the adoption of IFRS in 2013, FHC banks have shown a lower average AME compared to non-FHC banks. This discrepancy may be due to the fact that FHC banks, with their subsidiaries, might face constraints related to the marketability of the holding companies themselves. Therefore, FHC banks may need to implement strategies that enhance their market valuation and attract investor interest.

In conclusion, our findings suggest that individual banks in Taiwan tend to be more efficient than banks with diversified operations when both APE and AME are considered. This indicates that specialization may offer advantages over diversification in terms of overall efficiency.In application, as shown in Table 5, FHC bank A5's $NC-AOE_A$, $NC-APE_A$, and $NC-AME_A$ rank 1st among all the sample banks. This indicates that bank A5 is the benchmark bank for all the sample banks over the period 2013–2022. Clearly, A5 bank is relative to the other banks that achieves the best operational efficiency. Therefore, the other inefficient banks including FHC and non-FHC banks should learn from A5 bank in order to enhance their operational capabilities in terms of increasing OE, PE, and ME. Additionally, non-FHC bank B1's $NC-AOE_B$, $NC-APE_B$ and $NC-AME_B$ rank 2nd among all the banks. B1 bank apparently performs more efficiently than the other FHC and non-FHC banks except A5 bank. This means that although B1 bank is an independent bank, it could generate higher efficiency than the inefficient FHC banks within diversified organizations. Other inefficient banks should learn from B1 bank in terms of improving their OE, PE, and ME. In addition, FHC bank A1's $NC-AOE_A$ and $NC-AME_A$ rank 18th among all the sample banks. This means that bank A1 performs inefficiently within a diversified organization, implying that it does not enjoy any synergistic effects of diversification. Moreover, the $NC-APE_A$ of FHC banks A2, A3, A9, and A10 rank 3rd ,5th , 6th and 9th respectively among all the banks, while their $NC-AME_A$'s ranking lags considerably compared to that of the other banks (17th ,11th , 13th and 14th). Therefore, the managers of those banks should pay greater attention to improving their market values and avoid issues such as the agency problem, divisional rent-seeking, or top-management empire building (Jensen 1986; Rajan et al. 2000; Scharfstein and Stein 2000). In contrast, the $NC-AME_B$ of non-FHC banks B2, B3, B4, B5, and B8 (ranked 5th ,4th , 8th ,7th and 6th respectively) is much more efficient than their $NC-APE_B$ relative to other banks. Clearly, these banks should make greater efforts to enhance their capabilities in terms of profitability by carefully examining the cost structure of the bank, expanding loan activities to increase interest revenue, or developing diversified business strategies to create more fee-based income under IFRS.

With respect to the trend in changes in overall and two-stage efficiencies between FHC and non-FHC banks, the results are shown in Figs. 3–5. One can see that non-FHC banks perform more efficiently than FHC banks after they began preparing financial statements in accordance with the new standards in 2013. Moreover, compared to FHC banks, non-FHC banks are able to create better market value than FHC banks despite worse profitability capabilities. This indicates that the overall inefficiency of the banks is mainly affected by inefficiency in the marketability process; improvement in marketability efficiency is more important than improvement in profitability efficiency. This is consistent with the results shown in Table 5. Therefore, Taiwanese FHC banks should focus on increasing market value and instituting new management policies to avoid issues such as the agency problem, divisional rent-seeking or top-management empire building, as suggested by the literature (e.g., Jensen 1986; Rajan et al. 2000; Scharfstein and Stein 2000). In addition, as shown in Fig. 3, we can see that the $NC-AOE$ and $NC-APE$ of both systems of banks are in recession from 2021 to 2022. One possible reason for this is that the COVID-19 pandemic impacted both the FHC and non-FHC banks in terms of $NC-AOE$ and $NC-APE$ for the year 2022. As for the trend in changes in $NC-AME$, it is worth noting that FHC banks' $NC-AME$ has significant improvement from 2021 to 2022, while non-FHC banks' $NC-AME$ declines significantly from 2020 to 2022, indicating that investors are increasingly evaluating the market value of FHC banks, and FHC banks could keep trying to improve their marketability efficiency. Meanwhile, non-FHC banks have to pay more attention to reverse the decline in their market value.

The analysis results offer valuable insights into the relative strengths and weaknesses of banks. Since the adoption of IFRS in 2013, Taiwanese banks have had to adapt to new measurement standards for recognizing revenues and expenses in financial statements, as detailed in Table 1. This shift has altered the evaluation of bank operating efficiency and affected how capital markets perceive banks (Chao et al., 2015).

This study provides detailed insights into each production stage, highlighting areas where managers need to focus to enhance overall bank performance. FHC banks benefit from their diversified structures, which facilitate cross-selling, sharing of information technology, and e-commerce platforms, leading to increased revenue and reduced costs. Our empirical evidence demonstrates that FHC banks capitalize on the synergies of mergers, resulting in higher PE compared to non-FHC banks. In contrast, non-FHC banks, operating independently, lack such synergies but can still improve profitability by reducing costs and forming strategic alliances.

Overall, this study not only assesses the overall efficiency of banks but also evaluates the relative efficiencies of different production stages across varying organizational structures. The findings offer a valuable reference for identifying strengths and weaknesses and for guiding future improvements. Managers can use these evaluation results to adjust their operational strategies to enhance business performance and competitiveness under the new standards. Furthermore, the higher average profitability efficiency for FHC banks compared to non-FHC banks suggests that Taiwan's financial market has benefited from the FHC Act since its implementation in 2001, validating the positive impact of financial consolidation. However, the study also highlights that achieving high profitability while maintaining lower marketability efficiency remains a significant challenge for bank decision-makers. Policymakers should consider implementing stringent policies to improve the ME of Taiwanese commercial banks.

5. Conclusion

This study investigates whether Taiwanese commercial banks that are subsidiaries of FHCs improved their profitability efficiencies and market values following the adoption of IFRS in 2013. The findings have significant implications for Taiwan's current banking policies, which align with global accounting standards. Additionally, Taiwan's experience may serve as a valuable reference for other developing countries, such as those in Southeast Asia, preparing to adopt IFRS.

Given the distinct production technologies of FHC and non-FHC banks, employing a non-convex two-system NDEA model is more appropriate for analyzing the relative efficiencies of Taiwanese banks under different organizational structures. By constructing this non-convex two-system NDEA model, the study evaluates the efficiencies of various types of commercial banks (i.e., FHC banks and non-FHC banks) across different production stages (i.e., profitability and marketability).

The Mann-Whitney U test results for the sample period indicate that most annual PE and ME values for FHC and non-FHC banks are significantly different, whereas OE values are not significantly different post-IFRS adoption in 2013. The results reveal that FHC banks exhibit higher average PE compared to non-FHC banks, suggesting that FHC banks perform more efficiently in terms of profitability. This empirical evidence confirms that diversification under IFRS positively impacts profitability. However, FHC banks show significantly lower ME compared to non-FHC banks, likely due to their marketability being constrained by the holding companies' marketability. This finding raises concerns about the conglomerate discount.

As this study employs a static non-convex meta-frontier framework and does not account for potential period-to-period carry-over effects, future research could extend the current static two-system NDEA model based on the non-convex meta-frontier into a dynamic network framework.

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Appendix A. *A directional distance function NDEA model*

By considering a sample of K observed DMUs the specification of the activity analysis model satisfying constant returns to scale is given by:

$$\underset{\theta_1, \theta_2, \lambda_i, \mu_i, \tilde{z}}{Max} \frac{\theta_1 + \theta_2}{2} \quad (A-1)$$

s.t.

$$\sum_{k \in ALL} x_{ik} \lambda_k \le (1-\theta_1) x_{ik'}, k = 1, \ldots, K \quad (A-2)$$

$$\sum_{k \in ALL} z_{sk}^{1\to 2} \lambda_k \ge \tilde{z}, s = 1, \ldots, S \quad (A-3)$$

$$\sum_{k \in ALL} z_{sk}^{1\to 2} \mu_k \le \tilde{z}, s = 1, \ldots, S \quad (A-4)$$

$$\sum_{k \in ALL} y_{rk} \mu_k \ge (1+\theta_2) y_{rk'}, r = 1, \ldots, R \quad (A-5)$$

$$\lambda_k \ge 0, \mu_k \ge 0, k = 1, \ldots, K.$$

Model A is the classic model as introduced by Chen and Zhu[32] except for the fact that we use a directional distance function here instead of the radial measure. The main feature of Model A is the constant returns to scale (CRS) assumption and free link intermediates. If the specification of the activity analysis model satisfying variable returns to scale (VRS), fixed link intermediates, we can impose $\sum_{k \in A} \lambda_k = 1, \sum_{k \in A} \mu_k = 1$ and replace equation. (A-3) and (A-4) by $\sum_{k \in ALL} z_{sk}^{1\to 2} \lambda_k \ge z_{sk'}^{1\to 2}, s = 1, ..., S$ and $\sum_{k \in ALL} z_{sk}^{1\to 2} \mu_k \ge z_{sk'}^{1\to 2}, s = 1, ..., S$, respectively.

Appendix B.

Model 1 allows the DMUs to possibly have different characteristic types, and assumes the production possibility set to be unique. This is a key feature of the traditional approach of Chen and Zhu[31] starting from Fare and Grosskopf's[40] initial paper in 1996. However, Tone[11] has vigorously criticized that approach, due to the possibility that the efficient frontier is constructed from various non-homogenous production possibility sets. The issue is more reasonable when the efficient frontier is constructed from various non-homogenous production possibility sets.

Tone[11] proposed the non-convex frontier from different production possibility sets to measure the efficiency with non-homogenous frontier. The model can avoid the inaccuracy, in which the DMUs are separated into different production possibility sets by referring to homogenous frontier, which may result in some efficiencies being evaluated as inefficient while they are efficient, or vice versa.

As a matter of fact, the single system assumption does not apply to the practical which therefore needs to be explicitly introduced the different systems model proposed by Tone[11] in the aforementioned model. This way, the first and second technologies in network production possibility sets can be separated into two sub-systems. The two-system NDEA approach requires constructing the set T1, which captures the system A activities of firms, and the set T2, which captures system B production. We then seek the least outer boundary for these two-system efficiencies which is therefore interpreted as the maximum reduction of inputs and expansion of outputs can be projected on respective outer boundaries of the evaluated DMU. The efficient DMUs' maximum reduction rate θ_1 and expansion rate θ_2 are computed by referring to the outer boundary of non-convex and non-homogenous frontier of the system itself or the other system.

The two system network production possibility sets satisfying VRS is shown in Figure B1, B2, B3 and B4. There are four cases of the projection. Suppose DMU i achieves inefficiency, and the intermediate products produced in the first stage are an optimal $\tilde{z}$ at stage 1 instead of observed z. Then output expansion rate will be computed at the given $\tilde{z}$ at the second stage. Moreover, DMU i belongs to system A, DMU i's maximum reduction rate θ_1 is computed by referring to the outer boundary of non-convex and non-homogenous frontier of the system itself or the other, where θ_1 representing stage 1 inefficiency. While the expansion rate θ_2 is computed by referring to the outer boundary of non-convex and non-homogenous frontier of itself or the other, also θ_2 represents stage 2 inefficiency. As a result the DMUi's inefficiency, $w_1 \times \theta_1 + w_2 \times \theta_2$ is a maximum one by using non-symmetrical non-convex frontiers at stage 1 and stage 2. There are four possible cases for a specific inefficient DMU are illustrated below.

Case I: If the outer boundary is the system itself at both stage 1 and stage 2. The inefficiency score equal to $w_1 \times \theta_1^{itself} + w_2 \times \theta_2^{itself}$.

For example, in assessment of the efficiency of DMU i, as shown in Figure 2, at stage 1, when DMU i is belong to system A, suppose that the outer boundary is the frontier of system A, then it needs to refer to itself, so as to assess θ_1. Next, at the stage 2, suppose that the outer boundary also is the frontier of system A. As a result, DMU i's inefficiency score is calculated as $w_1 \times \theta_1^{itself} + w_2 \times \theta_2^{itself}$.

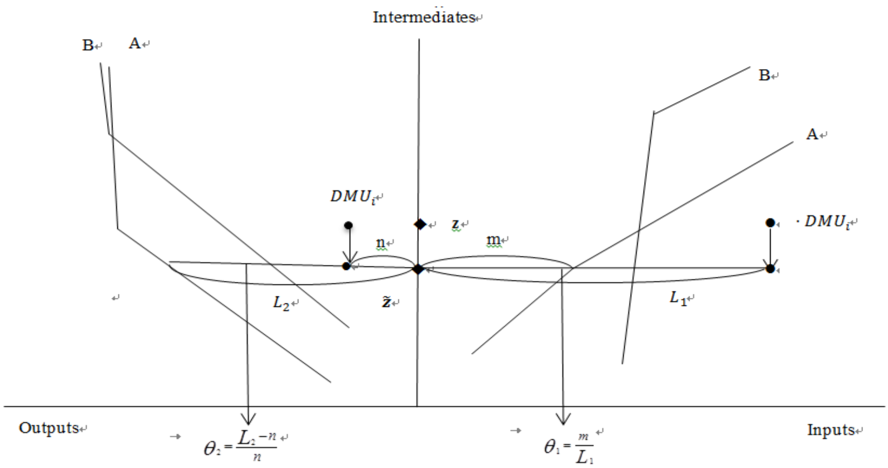

Figure B1. Two-system NDEA efficiency evaluation for Case I

Case II: If the outer boundary is the system itself at stage 1 and the other system at stage 2, in assessment of the efficiency of DMU i, as shown in Figure B1. The inefficiency score is equal to $w_1 \times \theta_1^{itself} + w_2 \times \theta_2^{other}$.

Following the same logic, the inefficiency score of DMU i is assessed in our two-system NDEA concept. When the DMU i belongs to system A, suppose that the outer boundary is the frontier of system A, then it needs to refer to itself, so as to assess θ_1. Next, at stage 2, suppose that the outer boundary is the frontier of system B. As a result, the DMU i's inefficiency score is calculated as $w_1 \times \theta_1^{itself} + w_2 \times \theta_2^{other}$.

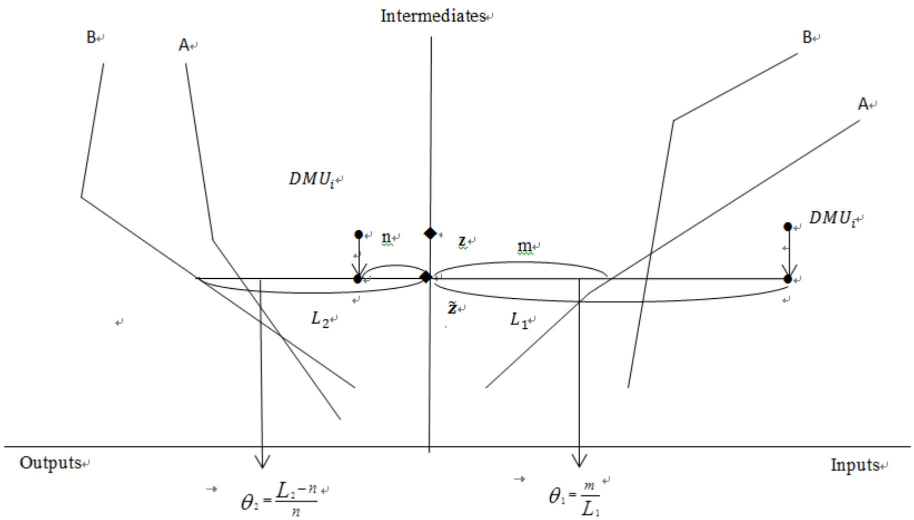

Figure B2. Two-system NDEA efficiency evaluation for Case II

Case III: If the outer boundary is the other system at stage 1 and system itself at stage 2, in assessment of the efficiency of DMU i, as shown in Figure B2. The inefficiency score is equal to $w_1 \times \theta_1^{other} + w_2 \times \theta_2^{itself}$.

Subsequently, suppose that the outer boundary with respect to DMU i is the frontier of system B, then it needs to refer to the other system, so as to assess its inefficiency score θ_1. Next, at stage 2, suppose that the outer boundary is the frontier of system A. As a result, the DMU i's inefficiency score is calculated as $w_1 \times \theta_1^{other} + w_2 \times \theta_2^{itself}$.

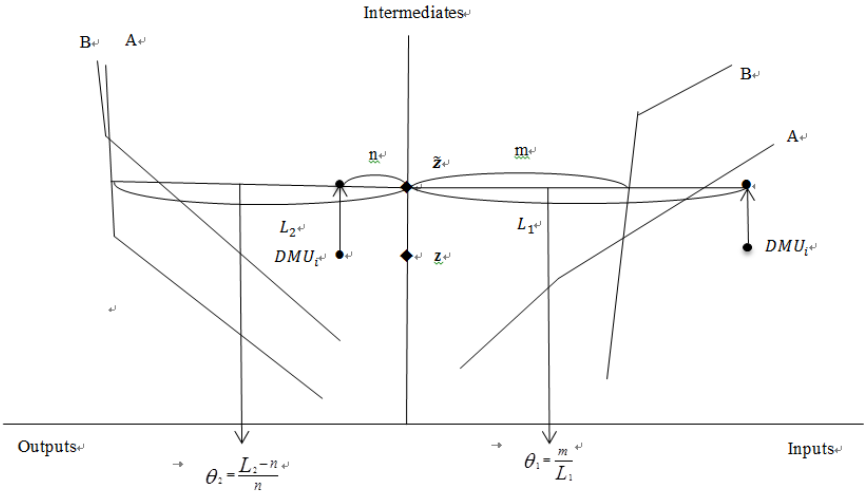

Figure B3. Two-system NDEA efficiency evaluation for Case III

Case IV: If the outer boundary is the other system both at stage 1 and stage 2 in assessment of the efficiency of DMU i, as shown in Figure B3. The inefficiency score is equal to $w_1 \times \theta_1^{other} + w_2 \times \theta_2^{other}$.

Once DMU k belongs to system B, the outer boundary is the frontier of system A at stage 1, then it needs to refer to the other system, so as to assess θ_1. Next, at stage 2, suppose that the outer boundary also is the frontier of system A. As a result, DMU i's inefficiency score is calculated as $w_1 \times \theta_1^{other} + w_2 \times \theta_2^{other}$.

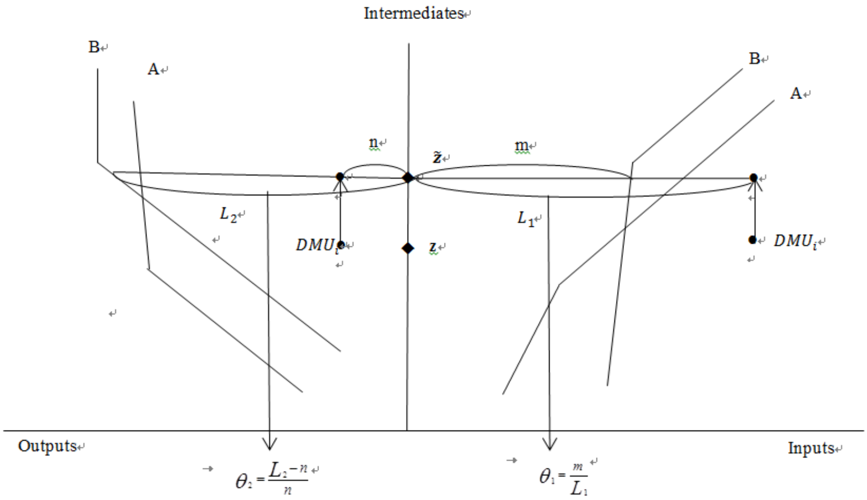

Figure B4. Two-system NDEA efficiency evaluation for Case IV

Appendix C.

Table C1. Name and Code for sample banks

Banks establishing or joining in FHCs		Banks with no establishing FHCs	
CTBC Bank Co., Ltd	A1	Kings Town Bank	B1
Taishin International Bank	A2	FarEastern International Bank	B2
E.SunCommercial Bank, Ltd.	A3	En Tie Commercial Bank	B3
Taiwan Shin Kong Commercial Bank	A4	Union Bank Of Taiwan	B4
TaipeiFubon Commercial Bank Co., Ltd.	A5	Taichung Commercial Bank	B5
Cathay United Bank	K6	Chang Hwa Commercial Bank	B6
Bank Sinopac Company Limited	A7	Bank of Kao Hsiung	B7
Hua Nan Commercial, Ltd.	A8	Taiwan Business Bank	B8
TaiwanCooperative Bank	A9		
First Commercial Bank	A10		

Appendix D.

As shown in Table D1, the Wilcoxon signed-rank test presents significant differences between TFAS & IFRS in terms of efficiency ranking. It can be found that the Wilcoxon signed-rank tests for FHC banks except MTGR between two sets of accounting standards show significant. It reveals that there is a clear impact on the conversion of accounting standards Taiwanese FHC banks. For non-FHC banks, the Wilcoxon signed rank tests of MOE and MPE present significantly different. While, the Wilcoxon signed-rank tests of MME, TGR, PTGR and MTGR present insignificantly different. Based on the statistical results, this study then uses 2012 financial statements, which for the first time, the accounting data under the new standard is used to explore the efficiency of two groups of banks in Taiwan.

Table D1. Wilcoxon signed-rank test for the difference of two-stage efficiencies under two sets of accounting standards in 2012 (TFAS & IFRS)

FHC banks	MOE	MPE	MME	TGR	PTGR	MTGR
z-value	-2.547	-2.016	-1.779	-2.028	-1.778	-0.944
p- value	0.011**	0.044**	0.075*	0.043**	0.075*	0.345
Non-FHC banks						
z-value	-1.992	-2.028	-0.365	-0.447	-0.447	-1.000
p- value	0.046**	0.043**	0.715	0.655	0.655	0.317

Note:TFAS : Taiwan financial accounting standard, MOE: meta OE; MPE: meta PE; MME: meta ME; TGR: Overall technological gap ratio; Profitability TGR: PTGR; Marketability TGR: MTGR, ** Significant at 5% level of significance, *Significant at 10% level of significance.