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Article

Mobile payment-banking efficiency nexus—A concise review of the evolution and empirical exploration of the Taiwan banking industry

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Abstract: This paper utilizes an advanced Network Data Envelopment Analysis (DEA) model to examine the impact of mobile payment on the efficiency of Taiwan banking industry. Inheriting the literature, we separate the banking operation process into two stages, namely profitability and marketability. Mobile payment is then considered as the core factor in the second stage. Our paper discovers network DEA model can effectively enhance the analysis of banking industry's efficiency, and mobile payment has a notable impact on Taiwan banking industry. Regarding the profitability stage, there is only one efficient bank in 2019 and 2022, respectively. These banks also perform better in terms of "mobile payment production". In the marketability stage, there is also only one bank in 2021 and one bank in 2022, that can reach to unique efficiency score. This indicates many banks attempt to increase earnings per share through investing in mobile payment services. However, the achievement still needs more wait. This leads to the fact that no bank can reach the ultimate overall efficiency. Within our sample, we also find that regarding promoting mobile payment services, Private Banks outperform Government Banks.

Keywords: mobile payment; profitability efficiency; marketability efficiency; network data envelopment analysis

1. Introduction

In recent years, the relentless introduction of novel financial technologies has engendered substantial qualitative transformations across various facets of the traditional financial industry, encompassing products, services, payments, transactions, credits, and operational processes (Niankara and Traoret, 2023). This transformation has been particularly propelled by remarkable advancements in communication technology and the widespread proliferation of mobile devices, leading to the emergence of mobile payment as a prevailing trend in transactional models (Le et al., 2022). Additionally, governments worldwide have been actively engaged in the process of opening up relevant laws and regulations to facilitate the transition towards a cashless society (Rahman et al., 2022). A pertinent exemplification of this trend is evident in China, where mobile payment services have become widely accessible, extending their reach from high-end fashion boutiques to local community newsstands. Utilizing the convenience of QR Code scanning, merchants can effortlessly conduct cashless transactions via smartphones, thereby challenging the established business models of global banks (Sleiman et al., 2023).

To allure the masses and enhance profitability, worldwide financial institutions have exerted considerable endeavors in the realm of mobile payment technology (Albashrawi and Motiwalla, 2019; Khan et al., 2016; Shareef et al., 2018). Nevertheless, it is noteworthy that the developmental emphasis and the extent of impact of mobile payment technology tend to vary across different periods and countries (Aloulou et al., 2023).

Hedman and Henningsson (2015) emphasized that the development of mobile payments constitutes a significant financial innovation that has reshaped the payment market within the mobile payments ecosystem. This innovation has attracted new payment service providers leveraging novel technologies to carve out their niches, while established traditional banking institutions seek to safeguard their oligopoly. In early 2010, the European Union introduced the mobile payment market cooperation (MPMC) framework, which engenders a dynamic interplay of mutual competition and collaboration among mobile phone manufacturers, telecommunications companies, traditional banks, and third-party payment entities within the mobile payment ecosystem (Bianchi et al., 2023). For instance, in the Netherlands, prominent banks and telecom operators have collaboratively undertaken a trusted service manager (TSM) project for mobile payment systems (Hasan et al., 2021). However, the success or failure of mobile payment platforms necessitates examination through the lens of collective action theory and platform theory to discern the intricacies of competition and cooperation between banks and telecom operators. Hedman and Henningsson (2015), therefore, highlights that divergent strategic goals, conflicting interests, and governance challenges can lead to the fragmentation of mobile payment platforms. Reuver et al. (2015) further underscored that the aforementioned issues within the mobile payment ecosystem can be partially attributed to the platform's openness to third-party payment operators and corporate governance considerations. Given the dominant presence of traditional large-scale banks in the consumer payments market in the Netherlands, competition predominantly unfolds between banks rather than between banks and telecom operators. This observation underscores the need for a comprehensive understanding of the interactions and dynamics between key stakeholders to comprehend the evolving landscape of mobile payment platforms.

In the Asian context, there is a growing focus on investigating the implications of mobile payments on both information security and consumer behavior, encompassing aspects related to user interfaces and mobile payment platforms. Scholars have increasingly directed their attention towards this domain. For instance, Lee and Chung (2009) employed a structural equation model (SEM) to examine South Korean users' trust and satisfaction with mobile banking. Their study incorporated influential factors, including system quality, user interface, and information quality. The findings revealed that the mobile payment platform's information security environment and the provision of fast and accurate information were pivotal factors significantly impacting user perceptions. Similarly, Zhou et al. (2021) conducted an online survey involving 224 customers of a large-scale Chinese bank. Their research demonstrated that the service quality of mobile banking has a direct and substantial influence on bank customer loyalty. Additionally, they observed that the user interface design of mobile banking wielded the most significant indirect effect in attracting consumers. The study also identified several crucial factors directly or indirectly

shaping consumers' preferences, among which user interface design, system quality, information security environment, and service quality played key roles. Al-Okaily (2023) undertook a comprehensive investigation into the determinants impacting users' e-loyalty within the domain of mobile payment technologies, specifically focusing on e-wallet payment apps. The empirical research employed a survey methodology administered to a cohort of 251 individuals utilizing e-wallet apps. The findings of this study significantly advanced the understanding of pivotal factors influencing e-wallet adoption, thereby proffering actionable recommendations aimed at augmenting the broader dissemination of financial technology. Indeed, the growing body of research signifies the escalating attention and interest in comprehending the multifaceted dimensions of mobile payment platforms and their implications for information security and consumer behavior in the Asian context.

The advent of mobile payment has brought about significant transformations in Taiwan's banking industry's financial service model (Lian and Li, 2021). In tandem with the introduction of internet banking, enabling customers to engage in financial transactions and wealth management through smartphones, banks are actively capitalizing on big data analysis to capitalize on the burgeoning mobile payment market. Despite these progressive initiatives, statistics from the Financial Supervisory Commission indicate that the proportion of electronic payment in the country still lags behind major countries in East Asia in recent years (Shang and Chiu, 2023). As a response to this situation, there is an imperative to intensify efforts in promoting the "Five-Year Doubling Electronic Payment Usage Rate" plan. Initially launched to double the original non-cash payment rate from 26% in 2015 to 52% in 2020, the plan has encountered challenges, primarily exacerbated by the disruptive impact of the COVID-19 pandemic. The inclusion of the "ATM transfer" project in 2020 only enabled a non-cash payment rate of 51.7%, falling short of the targeted standard. Therefore, there exists a pressing need to redouble initiatives and strategies to achieve higher rates of electronic payment adoption and bridge the gap with East Asian counterparts.

To comprehensively augment mobile payment adoption, the Taiwan Financial Supervisory Commission unveiled a three-year plan for non-cash payment in March 2021 (Fu et al., 2022). The overarching objective of this plan is to achieve substantial growth in the "non-cash payment transaction amount" by 8% annually, ultimately culminating in a total transaction value of 6 trillion NTD by the year 2023. Moreover, the plan aims to propel the "non-cash payment transaction number" by 50%, reflecting an impressive annual growth rate of 15%, thus attaining 7.832 billion transactions. Despite the challenges posed by the COVID-19 epidemic in Taiwan during 2021, the momentum towards increased non-cash payments remained robust, resulting in a notable yearly surge of 9.4%, with the amount of non-cash payments reaching 5.44 trillion NTD. This achievement signifies significant progress towards the Financial Supervisory Commission's target, effectively bringing the amount of non-cash payment transactions closer to the desired milestone by the conclusion of 2022.

The investigation regarding the influence of mobile payment activities on banking sector's performance has attracted significant scholarly attention. Despite a notable increase in research within this field in recent years, several gaps in the literature remain unaddressed. Firstly, the prevalent use of primary data, typically

derived from surveys, to represent the mobile payment variable, presents constraints for financial analysis. Secondly, the predominant reliance on regression models to assess the impact of mobile payments on performance raises concerns regarding the exogeneity of the mobile payment variable in relation to bank efficiency. Lastly, previous research often oversimplifies banking efficiency by primarily concentrating on financial metrics like Return on Assets (ROA) and/or Tobin's Q, rather than considering the multidimensional aggregate operational efficiency intrinsic to this complex industry.

This paper employs a two-stage Network DEA model to investigate the impact of mobile payment on the operating performance of Taiwan's banking industry. The additive efficiency approach proposed by Chen et al. (2009) is utilized, assuming both Constant Returns to Scale (CRS) and Variable Returns to Scale (VRS), to decompose total efficiency into individual efficiency scores. Subsequently, following the two-stage structure introduced by Seiford and Zhu (1999), the bank's profitability efficiency is examined in the first stage, while the bank's marketability efficiency is analyzed in the second stage. Through a detailed exploration of the internal operational processes, this study analyzes the source of inefficiency in actual business performance by scrutinizing efficiency values and weight values at individual stages. During the transition from the first stage to the second stage, the impact of mobile payment (as an intermediate measurement) is assessed using two key variables: "number of users" and "mobile payment electronic transaction volume". These variables serve as the focal points for analyzing the efficiency performance of individual stages. The quality of stage efficiency values and the magnitude of weight values significantly influence the overall operating performance of the bank, representing the central focus of this empirical research. Additionally, this article will compare the difference in the operating efficiency of public and private banks in Taiwan under the context of integrating mobile payment activities by employing the non-parametric Mann-Whitney U Test.

Our research contributes significantly in two key aspects. Firstly, it stands out as one of the few studies that systematically consolidates the literature on the development of electronic payments, with a specific emphasis on Taiwan market. It is noteworthy that Taiwan and China represent two markets characterized by substantial differences in the electronic payments ecosystem. While China, being a large market, has experienced early and extensive development of electronic payments (as extensively documented in the existing literature), the adoption of electronic payments in Taiwan is relatively in its early stages. Secondly, from an empirical perspective, our study utilizes datasets that directly capture mobile payment activities within Taiwanese banks, which are officially provided by the Taiwan Financial Supervisory Commission. Different from Tong et al. (2023), we incorporate the demand deposit variable as a crucial resource for mobile payment activities. Our model enables the efficiency decomposition capability for the network operation and elucidates the role/impact of mobile payment on the operational process in banking industry. Furthermore, the research's primary focus lies in assessing marketability rather than delving into the internal operational efficiency of banks.

The rest of this paper is structured as follows. In the second section, we introduce the operational aspects of mobile payment services and present an overview of

Taiwan's current payment market. The third section elucidates the efficiency decomposition method of the two-stage Network DEA model and outlines the analytical framework established for this study. Subsequently, the fourth section presents the empirical analysis of results, followed by the conclusion and recommendations in the final section.

2. Literature review

2.1. Mobile payment—Definition and some features

Mobile payment, in its comprehensive scope, constitutes a digital financial service that empowers users to conduct, authorize, and successfully complete financial transactions, while also facilitating seamless fund transfers through the utilization of mobile devices interconnected with the Internet or wireless communication technology (Slade et al., 2015). Commonly referred to as Mobile Payment Services (MPSs), these services encompass various forms such as mobile wallets, mobile remittances, contactless payments, or proximity payments, and have emerged as a rapidly expanding segment within the domain of mobile banking (Jung et al., 2020). By encompassing mobile wallets and mobile remittances, this technology enables secure and legitimate transactions via users' mobile devices, effectively obviating the necessity for physical cash, checks, or credit cards during payment processes, and effectively transitioning to digital payment methods (Alsmadi et al., 2022). Mobile payment applications can operate in both a "peer-to-peer" (P2P) environment, where users execute electronic transfers through banking channels, as well as in physical entities providing financial services. In P2P mobile payments, individuals can easily conduct electronic transfers through their banks, such as splitting restaurant bills or collectively purchasing event tickets via mobile devices. On the other hand, mobile payment at brick-and-mortar outlets involves users making payments for specific goods or services at the checkout counter, leveraging a dedicated mobile app instead of cash or credit cards. Businesses offering this payment method require specific point-of-sale (POS) equipment to process transactions efficiently.

Research findings suggest that among MPSs, those leveraging personal social networks are notably more prevalent among young adults in the United States compared to other types of MPSs. Moreover, the adoption of MPSs by users is influenced by several key factors, including expected performance, specialization, trust, compatibility, and community influence. The implications of these studies hold substantive significance for the development of the financial industry (Jung et al., 2020). Additionally, other scholarly investigations have underscored the paramount importance of expected efficacy in determining users' inclination to adopt MPSs (Koenig-Lewis et al., 2015; Musa et al., 2015; Slade et al., 2015; Tan et al., 2014; Teo et al., 2015). Furthermore, the surge in mobile payment apps in recent years is unsurprising, given users' increasing reliance on mobile devices for various daily activities, including messaging, public transportation, and health data monitoring. This growing reliance on mobile devices has fostered a receptive environment for the proliferation of mobile payment applications.

2.2. Current situation of mobile payment in Taiwan

In 2017, the Financial Supervisory Commission (FSC) and the Ministry of Finance jointly introduced Taiwan Mobile Payment (Taiwan Pay), a collaborative effort involving numerous domestic financial institutions, with the primary objective of penetrating the financial card payment market. Taiwan Pay integrated the functionality of financial card payments into mobile phones, offering a common platform based on the "QR Code Common Payment Standard" application development. The service targeted users without credit cards, categorized as an electronic payment service. It prioritized the introduction of Taiwan Pay services for various livelihood-related expenses, including water, electricity, parking fees, and taxes, in addition to general consumption. The initiative aimed to leverage this advantage and establish itself as a national payment brand, encouraging wider adoption of mobile payment services among the population. However, despite such advantages, the usage rate of mobile payment in Taiwan has not seen a notable increase. The main impediment lies in the fact that Taiwan Pay operates as an open payment system, connecting to various banks, resulting in difficulties in seamless integration. Furthermore, the imperfect user interface hinders the overall user experience, leading to inconvenience and restrictions in its use.

In recent years, Taiwanese banks have actively sought to enhance their presence in the mobile payment market by pursuing various strategies. Besides collaborating with payment companies, some banks have also ventured into developing their independent mobile payment services. In alignment with the "Regulations on the Administration of Electronic Payment Institutions", companies are permitted to apply for licenses to provide electronic payment services if they facilitate users in registering and opening electronic payment accounts as intermediaries for fund transfers, value storage, and transmitting receipt and payment messages through electronic devices. These services include operations such as "receipt and payment of actual transaction funds", "receipt of stored value funds", and "transfer between electronic payment accounts", which facilitate seamless transactions between payers and payees. These electronic payment services can be offered through cross-industry alliances or by the banks themselves. However, technical challenges have prompted most banks to form collaborations with electronic payment operators to facilitate the implementation of their mobile payment initiatives.

From an industry-wide perspective, the implementation of the new "Regulations on the Administration of Electronic Payment Institutions" on 1 July 2021, marks a significant milestone in Taiwan's electronic payment development (Lian and Li, 2021). With the successful integration of the new electronic checks and electronic check systems, a crucial phase has been initiated. A financial company has been entrusted with building an inter-agency sharing platform for electronic payments, with Taiwan Cooperative Bank designated as the responsible entity for account settlement. This integrated platform encompasses various functionalities, including the national fee payment platform, fund transfer platform (enabling inter-bank account information inspection, agreed links, and deductions), QR Code common payment (facilitating cross-border remittances and transactions), and online shopping capabilities. Furthermore, this development facilitates seamless transfers between different

electronic payment platforms, alongside the introduction of foreign currency trading, domestic and foreign small-amount exchanges, and the integration and discounting of bonus points. These advancements contribute significantly to the Financial Supervisory Commission's objective of effectively managing and controlling risks associated with physical and virtual stored value tools. Consequently, the expansion of the electronic payment and electronic ticket payment ecosystem is poised to be achieved successfully.

The prevalence of mobile payment usage in Taiwan is progressively increasing, creating novel prospects for the electronic payment industry. According to the 2021 mobile payment consumer survey conducted by the Institute for Information Industry, the percentage of Taiwanese individuals favoring card payments declined from 35% in 2020 to 26% in 2021. This observation indicates that mobile payment has evolved from being merely a technological trend to an integral part of daily life. Several factors contribute to this transformation: firstly, the contactless transaction model, driven by the pandemic, has played a significant role. Secondly, major retail outlets and prominent e-commerce players like PX Mart, Family Mart, 7-11, Shin Kong Mitsukoshi, Carrefour, Shopee, etc., have all ventured into self-operated payment channels over the past couple of years, which, in conjunction with the growth of delivery platforms, has expanded the application scenarios for mobile payment (Fu et al., 2022). Additionally, this momentum has hastened the Financial Supervisory Commission's approval for the establishment of two exclusive electronic payment institutions, namely PXPay Plus and QuanYing+Pay (two of the earliest electronic payment solutions providers founded in Taiwan). This shift in consumer behavior and the industry's response have solidified the integration of mobile payment into everyday life in Taiwan.

The implementation of the new "Regulations on the Administration of Electronic Payment Institutions" is expected to bring about three significant changes in the application scenarios of electronic payment. These changes include cross-institutional cash flow, such as transfers between JKOPAY accounts and Easy Card accounts, value storage, and transfers in foreign currency, such as exchanging US dollars for New Taiwan dollars, and trading of financial products.

Currently, the Financial Supervisory Commission has granted electronic payment licenses to 28 institutions including 19 banks forming the sample for this research. The exclusion of other institutions from the sample is primarily due to the unrelated nature of their business and limited data availability. Most banks are actively engaged in the realm of mobile payment. Although the banking industry has yet to lead in mobile payment branding, it holds the potential to diversify its reliance on mainstream mobile payment companies by venturing into the sales of derivative financial products and establishing its member services in the long term. Consequently, launching self-operated mobile payment services enables banks to broaden their collaborative partnerships across various industries. As a result of such cooperation, consumers are presented with a wider array of choices within different sectors, enhancing the overall versatility of the mobile payment ecosystem.

2.3. The network DEA and performance of banking industry

DEA is a robust approach used for evaluating the relative performance of individual Decision-Making Units (DMUs) concerning multiple input and output variables. In recent years, DEA has gained widespread popularity in management and financial research. However, traditional DEA models, such as the CCR model (Charnes et al., 1978) and BCC model (Banker et al., 1984), solely focus on the conversion process of input and output for each DMU, thereby overlooking the internal operational processes from input to output. This limitation may result in potential errors in efficiency estimation outcomes. Consequently, scholars such as Färe and Grosskopf (1996) and Tone and Tsutsui (2007) have ventured into exploring the internal structure of DMUs across various industries, giving rise to the development of the Network DEA models. These models aim to capture the intricacies of the internal operations within DMUs and offer a more comprehensive and accurate assessment of their efficiency scores. By adopting the Network DEA, this study, therefore, endeavors to provide a thorough evaluation of how mobile payment impacts the operating efficiency of Taiwan's banking industry.

The internal structure proposed in the literature of Network DEA exhibits a noteworthy complexity, encompassing a range of structured networks, including series and parallel configurations, as well as unstructured arrangements. In the context of sequential or vertical networks, different structures like two-stage, multi-stage, or hybrid frameworks have been explored in prior research (Tone and Tsutsui, 2007). For the purpose of this paper, the model design adopts a serial two-stage structure as its basis.

Regarding the two-stage Network DEA model, Ruggiero (1998) elucidated that the internal structure typically aims to explore DMUs in specific circumstances or contexts, with a particular emphasis on the second stage. This aspect allows for an analysis of the influence of environmental variables, external variables, discretionary variables, and classification variables on the stage efficiency value. An illustrative application of this approach is demonstrated by Kao and Hwang (2008) in their investigation of the efficiency of 24 insurance companies in Taiwan. They formulated a network structure comprising two stages, where the first stage assessed the efficiency of market capacity, while the second stage examined the efficiency of profitability.

Within the present literature concerning banking performance assessment using the DEA, two primary research directions emerge. The first direction employs conventional DEA models in its first stage to estimate operational efficiency, followed by the application of a regression model, such as Tobit, to explore the determinants impacting those efficiency scores. Abidin et al. (2021) differentiates the efficiency between Conventional Banks and Regional Development Banks in Indonesia. Their investigation underscored the significant influence of Return on Assets (ROA) solely on Conventional Banks, whereas Regional Development Banks were found to be affected by both ROA and non-performing loans. In a similar vein, Endri et al. (2022) conducted an evaluation and analysis of the factors influencing the efficiency of Islamic Rural Banks in Indonesia. Conversely, the alternative approach delves into an exploration of the factors shaping bank efficiency by dissecting their contributions within a framework, conceptualizing banking operation as a network. Seiford and Zhu

(1999) employed a two-stage Network DEA to investigate the profitability and marketability performance of large commercial banks in the US. It utilized a sample of the top 55 banks in 1995. Empirical findings revealed that nearly 90% of the large commercial banks exhibited inefficiencies in both the profitability stage and the marketability stage. Moreover, a considerable proportion of these banks demonstrated diminishing scale efficiency in the marketability stage, while some showcased increasing scale efficiency in the profitability stage. Consequently, the study inferred that bank size might hurt the marketability stage. In a similar vein, Luo (2003) also employed the two-stage Network DEA model to scrutinize the operating performance of 245 large banks in the US. The research findings indicated relatively poor performance among the current large banks concerning the second stage of marketability efficiency. Furthermore, the study identified that 34 banks (approximately 14% of the sample) exhibited relatively high profitability efficiency in the first stage; however, their market performance in the second stage did not align with expectations, thus falling short of being satisfactory.

3. Network DEA and research model

The implementation of DEA has long been recognized as one of the most effective methods for evaluating the operational performance of individual DMUs. In recent years, researchers in the field of Network DEA have dedicated considerable effort to exploring the intricacies of DMUs in various specific contexts. In this pursuit, mathematical models have been devised, leading to different solutions and decomposition pathways. For instance, in the case of two-stage networks, two primary decomposition methods have been developed. The first method defines the overall efficiency as the multiplicative combination of efficiency values for the two stages. This approach was initially employed by the renowned pioneers Kao and Hwang (2008) in their mathematical model for efficiency calculations, yet it is limited to scenarios with constant returns to scale.

The other approach is the linear additive method, where the total efficiency is expressed as the weighted average of the efficiency of each stage. Chen et al. (2009) pioneered this method, expanding upon Kao and Hwang (2008)'s work. This approach allows for the consideration of both constant return to scale and variable return to scale simultaneously and can be widely applied to network DEA involving more than two stages (Cook et al., 2010), thereby offering distinct advantages in empirical applications. In this paper, the mathematical model adopted follows the summation method proposed by Chen et al. (2009).

3.1. Solution for the two-stage network DEA structure

Since its introduction by Charnes et al. (1978). In 1978, DEA has been emerged as a widely employed method for assessing the relative efficiency of the DMUs. Concurrently, researchers have devoted considerable efforts to investigating the underlying factors influencing relative inefficiency in operational processes. Particularly, there has been a growing interest among scholars in unveiling the "black box" of DMUs, aiming to elucidate the sources of inefficiency by dissecting the components of total efficiency. Within the existing literature, the study of overall

efficiency solution and disassembly constitutes the two principal categories of research in this domain.

Initially, Banker et al. (1984) undertook an analysis of the internal structure of the DEA model, wherein they deconstructed the overall efficiency of DMUs into the product of scale efficiency and technical efficiency. Subsequently, this line of inquiry is further extended by decomposing the total efficiency into the weighted arithmetic mean of the efficiency values associated with individual output items. These investigations collectively contribute to a comprehensive understanding of the diverse methods utilized in disentangling the components of total efficiency within the DEA framework.

Another strand of research places emphasis on considering the production process as a composite of multiple stages. Consequently, the intricate overall production process can be dissected into individual sub-processes for detailed analysis. Within this significant line of inquiry, certain intermediate measures are designated both as the output items of the preceding stage and as the input items of the subsequent stage. Notably, pioneering works, such as Färe and Grosskopf (1996) or Seiford and Zhu (1999), have delved into this approach, shedding light on the benefits of scrutinizing sub-processes to gain deeper insights into the complexities of the overall production process.

When delving into the complexities of the overall production process, one of the simplest cases involves a tandem (serial) system, as depicted in **Figure 1**. This system comprises two distinct sub-processes that are not operated in isolation but are interconnected. Seiford and Zhu (1999) adopted this system as a basis to explore the overall production process of the top 55 large commercial banks in the United States, deconstructing it into two stages: the profitability stage and the marketability stage for in-depth analysis. Notably, whether conducting an efficiency analysis for the profitability stage, the marketability stage, or the overall production process's total efficiency, all three investigations were treated as individual independent DEA models. Zhu (2000) similarly employed this methodology to examine the financial efficiency of the top 500 companies featured in Fortune Magazine.

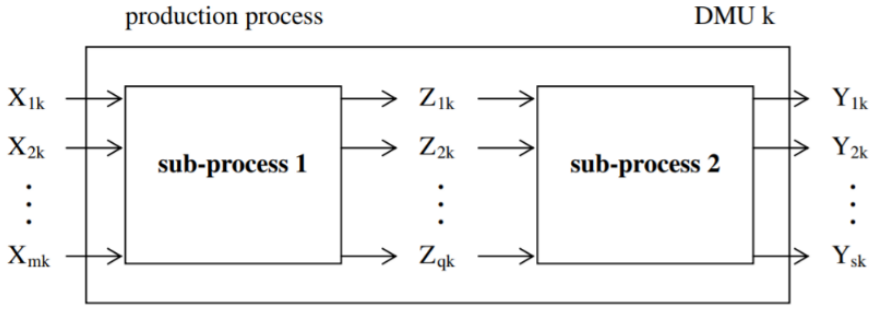

Figure 1. General two-stage network DEA model.

Indeed, the application of the independent two-stage DEA model has extended to various domains, including the analysis of Major League Baseball teams (Sexton and Lewis, 2003), information technology (Chen and Zhu, 2004; Chen et al., 2006), and property insurance (Kao and Hwang, 2008). Building upon this foundation, Liang et al. (2008) further explored the mathematical decomposition method of total efficiency,

introducing Game theory concepts to devise two DEA models and efficiently decompose efficiency.

This paper adopts an approach proposed by Chen et al. (2009), as a subsequent advancement, for determining the overall efficiency value of DMUs by calculating the weighted sum of efficiency values for each stage, as opposed to using a simple product of these values. This novel method offers additional benefits, as the analysis of the weights assigned to each sub-stage allows for the identification of the relative "importance" of these sub-stages. Such insights are valuable for understanding resource allocation across stages and assessing the potential causes of operational inefficiency. By employing a weighted approach rather than a simple arithmetic mean to combine the sub-stage efficiencies, this method takes into account the significance of each sub-stage and contributes to a more nuanced and insightful assessment of overall efficiency.

Let's denote θ_0^A, θ_0^B as the efficiency of the first stage and the second stage of DMU0. They are, therefore, written as follows,

$$\begin{gathered} \theta_0^{A*} = Max \frac{\sum_{d=1}^{d_{AB}} \eta_d^{AB} z_{d0}^{AB}}{\sum_{i=1}^{i_A} v_i^A x_{i0}^A} \\ s.t. \sum_{d=1}^{d_{AB}} \eta_d^{AB} z_{dj}^{AB} \le \sum_{i=1}^{i_A} v_i^A x_{ij}^A \quad \forall j \\ \eta_d^{AB}, v_i^A \ge \varepsilon \end{gathered} \tag{1}$$

and

$$\begin{gathered} \theta_0^{B*} = Max \frac{\sum_{r=1}^{r_B} u_r^B y_{r0}^B}{\sum_{d=1}^{d_{AB}} \eta_d^{AB} z_{d0}^{AB}} \\ s.t. \sum_{r=1}^{r_B} u_r^B y_{rj}^B \le \sum_{d=1}^{d_{AB}} \eta_d^{AB} z_{dj}^{AB} \quad \forall j \\ \eta_d^{AB}, u_r^B \ge \varepsilon; \end{gathered} \tag{2}$$

wherein, *n* represents the number of *DMUs* selected for evaluation (with *j = 1, 2, ..., n*), the final constraints ensure that all weighted variables must be positive (where ε is a constant greater than zero).

The denominator of Equation (1) represents the inputs (*X*) of the first stage, while the numerator corresponds to the outputs (*Z*). These outputs, then, are absorbed to generate the final products of the system, namely, *Y*. The relationship between the first and second stages is represented by their corresponding weights.

$$\begin{aligned} w_A &= \frac{\sum_{i=1}^{i_A} v_i^A x_{i0}^A}{\sum_{i=1}^{i_A} v_i^A x_{i0}^A + \sum_{d=1}^{d_{AB}} \eta_d^{AB} z_{d0}^{AB}} \\ w_B &= \frac{\sum_{d=1}^{d_{AB}} \eta_d^{AB} z_{d0}^{AB}}{\sum_{i=1}^{i_A} v_i^A x_{i0}^A + \sum_{d=1}^{d_{AB}} \eta_d^{AB} z_{d0}^{AB}} \end{aligned} \tag{3}$$

It is essential to emphasize that the weight assigned to each stage is determined by dividing the virtual resources of that stage by the total resources of the two-stages system, and their summation is unique, that is $w_A + w_B = 1$.

If we denote θ_0^{AB} as the system's overall efficiency, this score is decomposed as the combination of stage A and stage B's efficiencies and their weights.

$$\theta_0^{AB} = w_A\theta_0^A + w_B\theta_0^B = \frac{\sum_{d=1}^{d_{AB}} \eta_d^{AB} z_{d0}^{AB} + \sum_{r=1}^{r_B} u_r^B y_{r0}^B}{\sum_{i=1}^{i_A} v_i^A x_{i0}^A + \sum_{d=1}^{d_{AB}} \eta_d^{AB} z_{d0}^{AB}} \quad (4)$$

Building upon this idea, the overall efficiency of a DMU can be solved through the following mathematical programming formulation.

$$\begin{gathered}
\theta_0^{AB*} = Max \frac{\sum_{d=1}^{d_{AB}} \eta_d^{AB} z_{d0}^{AB} + \sum_{r=1}^{r_B} u_r^B y_{r0}^B}{\sum_{d=1}^{d_{AB}} \eta_d^{AB} z_{d0}^{AB} + \sum_{i=1}^{i_A} v_i^A x_{i0}^A} \\
s.t. \sum_{d=1}^{d_{AB}} \eta_d^{AB} z_{d0}^{AB} + \sum_{i=1}^{i_A} v_i^A x_{i0}^A = 1 \\
\sum_{d=1}^{d_{AB}} \eta_d^{AB} z_{dj}^{AB} \le \sum_{i=1}^{i_A} v_i^A x_{ij}^A \quad \forall j \\
\sum_{r=1}^{r_B} u_r^B y_{rj}^B \le \sum_{d=1}^{d_{AB}} \eta_d^{AB} z_{dj}^{AB} \quad \forall j \\
\sum_{d=1}^{d_{AB}} \eta_d^{AB} z_{dj}^{AB} + \sum_{r=1}^{r_B} u_r^B y_{rj}^B \le \sum_{d=1}^{d_{AB}} \eta_d^{AB} z_{dj}^{AB} + \sum_{i=1}^{i_A} v_i^A x_{ij}^A \quad \forall j \\
v_i^A, u_r^B, \eta_d^{AB} \ge \varepsilon
\end{gathered} \quad (5)$$

3.2. Framework design and variables selection

This study adopts the decomposition approach proposed by Chen et al. (2009) and applies the two-stage process setting model employed by Seiford and Zhu (1999), as illustrated in **Figure 1**. The selection of variables pertinent to electronic payments, with a specific emphasis on mobile payments, by financial institutions has constituted a widely debated subject within the scholarly discourse. Stoica et al. (2015) undertook an investigation examining the ramifications of internet banking on the operational efficiency of the banking sector in Romania. In this inquiry, the authors utilized a model in which the average daily "reach" rate for internet banking websites functioned as the principal output variable, serving as a gauge for the effectiveness of internet banking operations. However, the use of this variable as a proxy poses challenges in accurately gauging the efficiency of non-cash payment activities, given the inherent difficulty in ascertaining the precise motivations underlying access to a bank's website. Le and Ngo (2020) asserted that variables representing non-cash transaction tools, including the number of issued cards, quantity of ATMs, and POS machines, exert a substantial positive influence on a bank's profitability. These variables, viewed from a production-oriented perspective, signify investments in payment channels rather than the intrinsic efficiency of cashless payment operations. In a complementary vein, Tong et al. (2023) employed variables that offer a more precise reflection of mobile payment activities, namely the number of mobile payment users and electronic financial transaction volume. This study adopts the intermediation approach, where variables related to mobile payments and deposits are harnessed to generate traditional bank outputs, encompassing lending, investment, and non-interest income.

The banking performance evaluation framework employed in this research focuses on scrutinizing the relationship between two main stages, namely Profitability and Marketability. This conceptual framework draws upon the perspectives delineated by Seiford and Zhu (1999). According to this framework, banks initially strive to

optimize their profit and promote their comparative advantage products, following which their outputs are assessed by the financial market through market-oriented indicators. The originality of this study lies in the incorporation of variables delineating mobile payment activities, serving as a bridge that links the Profitability and Marketability stages. The ideology behind this notion is that the financial market accords significance to mobile payment activities as a pivotal determinant of banks' essential progression. Specifically, in the initial stage, except for the two well-accepted inputs—equity (X1) and total employee expenses (X2), we employ demand deposits (X3) as the the primary source of mobile payments. These inputs are combined to produce traditional outputs, namely total revenues (Z1), as well as mobile payment-specific outputs, that are the number of mobile payment users (Z2), and the volume of electronic financial transactions (Z3). Our key concerned variable—mobile payment—is treated as both output in the first stage and input for the second stage. As a result, Z2 and Z3 signify the outcomes of banks' endeavors in promoting and utilizing mobile payment. Importantly, these outcomes exert a direct influence on the market efficiency in the subsequent stage of each bank. In line with the current regulations in Taiwan, electronic payment enables fund transfers and value storage between different accounts. Prior to utilizing electronic payment methods for transactions, customers are required to bind their payment accounts (account link) and complete verification using payment tools such as bank accounts or credit cards. As a result, a higher number of mobile payment users or a greater electronic financial transaction volume signifies an association with enhanced profitability and heightened market development capabilities. The model's variables definition for the inputs X, intermediate measures Z, and outputs Y is provided in **Table 1**.

Table 1. Definition of variables.

	Variable	Unit	Definition and Source of Data
Inputs	Equity (X1)	10^6 NTD	The owner's equity – total assets minus total liabilities (TEJ).
	Total employee expenses (X2)	10^6 NTD	The total amount of employee expense of the company for the year (TEJ).
	Demand deposit (X3)	10^6 NTD	The total amount of check deposit and demand deposit (TEJ)
Inter-mediate	Total Revenues (Z1)	10^6 NTD	Total revenues from all bank's operations (TEJ)
	No of Users (Z2)	Thousand people	The number of users who have registered and opened an electronic payment account and have not yet terminated the contract – montly average (Taiwan FSC).
	Electronic transaction volume (Z3)	10^3 NTD	The total amount of money that the electronic payment institution provides for the service of receiving and paying transaction funds on behalf of the user during a year (Taiwan FSC).
Outputs	Net Income (Y1)	10^6 NTD	Total of net interest income plus net non-interest income (TEJ)
	EPS (Y2)	NTD	Earning per Share – Preferred Stock Dividend/weighted average number of issued stocks (TEJ)

Note: TEJ stands for Taiwan Economic Journal—one of the most comprehensive financial database of Taiwanese firms.

At this juncture, the first stage pertains to the bank's profitability analysis. The outputs encompass total revenues, along with the number of mobile payment users and electronic financial transaction volume. These three outputs are referred to as intermediate measures and serve as the inputs for the second stage's marketability

efficiency analysis. In this stage, banks focus on establishing reputation in the financial market. A thriving financial business, characterized by an increased number of bank accounts linked to opening accounts and higher financial transaction volumes, such as online deposits and securities accounts, not only enables undertaking larger corporate loans but also augments asset management profits, thereby generating heightened market efficiency.

Recently, banks have shown a dedicated commitment to enhancing the flexibility of digital finance and virtual channel services, encompassing online platforms, digital accounts, and mobile payment facilities. The advancement of financial technology has enabled a more precise and real-time response to financial consumers' needs. Additionally, there has been a notable increase in the proportion of business conducted by banks through virtual channels. As a result, the integration of virtual and physical aspects, alongside the analysis of operational performance and resource allocation within physical branches, necessitates more efficient assessments. Furthermore, various stakeholders, including regulators, policymakers, bank managers, and investors, have come to recognize the significance of appropriate measures and technology utilization in bolstering banks' financial stability and long-term performance (López-Penabad et al., 2022).

4. Empirical results analysis

The data for this study were collected from the annual reports of various banks for the years from 2019 until 2022, along with information sourced from the Financial Supervisory Commission's official website and the Taiwan Economic Journal (TEJ) database. The assessment sample comprises 19 banks that have been licensed by the Financial Supervisory Commission to operate electronic payment institutions. Descriptive statistics of the variables used in the model is shown in **Table 2**.

Table 2. Variables' descriptive statistics.

	Variables	**Mean**	**Median**	**St.D.**	**Min**	**Max**
Inputs	Equity (X1)	188.316	189.831	91.246	32.788	402.191
	Total employee expenses (X2)	12.116	12.234	6.432	2.281	35.254
	Demand deposit (X3)	1117.9	1159.9	518.7	229.4	2335.5
Inter-mediate	Total Revenues (Z1)	52.174	53.122	26.721	10.769	144.778
	No of Users (Z2)	108.615	2.226	306.663	0.038	1607.916
	Electronic transaction volume (Z3)	100.327	7.698	354.979	0.143	1718.270
Outputs	Net Income (Y1)	40.100	38.638	21.967	7.484	118.767
	EPS (Y2)	1.596	1.430	0.636	0.630	3.500

This study employs Lingo 18 to develop a dedicated program for the comprehensive assessment of 19 banks operating in Taiwan during the years 2019 and 2022. The evaluation primarily focuses on three critical dimensions: profitability efficiency, marketability efficiency, and overall efficiency. To enhance the clarity of our analysis, we include the bank code in the initial column of the table, while the efficiency values are indicated within the right square brackets to signify their respective rankings.

4.1. Profitability efficiency analysis

Based on the model presented in **Figure 1** and the data provided in **Table 2**, three primary input factors influencing profitability are equity (X1), total employee expenses (X2), and demand deposit (X3). On the other hand, the output metrics under consideration consist of total revenues (Z1), the number of mobile payment users (Z2), and electronic financial transaction volume (Z3). Consequently, the crux of profitability efficiency hinges on the ability of each bank to optimize its inputs efficiently, yielding maximum revenues and transactional outcomes. To gain deeper insights into the determinants of profitability efficiency for each bank, we draw upon empirical findings from the tables and scrutinize the operational and financial data disclosed in the annual reports published by Taiwan's banking industry on an annual basis. This approach allows us to unravel the underlying factors shaping the profitability efficiency of these financial institutions.

Table 3 presents a comprehensive overview of the profitability efficiency scores for the 19 banks during the years 2019 to 2022. Notably, our empirical findings reveal that in 2019, four banks achieved a stage efficiency value of 1. Similarly, the number of "efficient" banks in 2022 is five. Among these, CTBC Bank and Taipei Fubon Bank are the only two banks that maintained unique efficiency scores in these two years. Towards the lower end of the efficiency ranking, we observe the inclusion of several sizable financial institutions, namely Hua Nan Bank, Chang Hwa Bank, Yuanta Bank, and Mega Bank. Notably, these banks exhibit an efficiency score range typically hovering between 0.5 and 0.6, indicating a relatively lower level of efficiency when compared to their counterparts in the study.

An examination of the five banks that exhibited perfect profitability efficiency in 2022, reveals noteworthy trends. During this period, there was a noticeable uptick in electronic financial transaction volumes related to mobile payments, accompanied by a substantial surge in the number of mobile payment users. Notably, except Cathay Bank, all of these others demonstrated an increase in their mobile payment user base which displayed a relatively stable performance in this regard.

Furthermore, we observed significant developments in the profitability performance of the 19 banks within the initial stage of assessment, particularly in 2022. Notably, the number of banks achieving a stage efficiency value of 1 increased during this period. Furthermore, our findings highlight marked improvements in the profitability performance of Taishin Bank. Not only did the bank attain a stage efficiency value of 1, but it also ascended to a shared first-place ranking. Noteworthy progress was evident in several key metrics for Taishin Bank in the profitability stage of 2022. Specifically, its revenues, number of mobile payment users, and electronic financial transaction volume all experienced substantial growth. Notably, the number of mobile payment users doubled, while the electronic financial transaction volume increased by a noteworthy 50%.

Within the computation of a bank's overall efficiency, the stage weight value assumes significance as it reflects the relative contribution of each stage's efficiency performance. This value holds implications for the allocation of resources within the bank's overarching business strategy (Chen et al., 2009). A noteworthy observation emerges from this analysis: the emphasis placed on profitability by the 19 banks

exhibited a relative increase. However, paradoxically, the average profitability efficiency declined during this period. This divergence suggests that the allocation of resources may not have yielded the optimal benefits, underscoring the need for a more effective resource utilization strategy.

Table 3. Profitability efficiency scores and their weights of the 19 Taiwan banks.

Banks	2019			2020			2021			2022			Mean Eff.
	Weight	Eff.		Weight	Eff.		Weight	Eff.		Weight	Eff.		
5858 Bank of Taiwan 臺銀	0.535	0.868	(14)	0.588	0.699	(13)	0.620	0.614	(14)	0.540	0.851	(12)	0.758
5857 Land Bank of Taiwan 土銀	0.512	0.953	(7)	0.563	0.776	(8)	0.573	0.745	(8)	0.506	0.977	(7)	0.863
5854 Taiwan Cooperative Bank 合庫	0.562	0.778	(17)	0.606	0.650	(16)	0.628	0.592	(15)	0.563	0.776	(16)	0.699
5844 First Bank 一銀	0.556	0.799	(15)	0.601	0.665	(15)	0.613	0.631	(13)	0.544	0.839	(13)	0.733
5838 Hua Nan Bank 華銀	0.576	0.737	(19)	0.628	0.592	(18)	0.639	0.565	(16)	0.557	0.797	(15)	0.673
2801 Chang Hwa Bank 彰銀	0.564	0.773	(18)	0.629	0.589	(19)	0.658	0.519	(18)	0.579	0.729	(18)	0.652
5876 Shang Hai Bank 上海商銀	0.500	1.000	(1)	0.533	0.877	(3)	0.577	0.734	(9)	0.538	0.858	(11)	0.867
5836 Taipei Fubon Bank 台北富邦銀	0.500	1.000	(1)	0.525	0.905	(2)	0.549	0.820	(2)	0.500	1.000	(1)	0.931
5835 Cathay United Bank 國泰世華	0.506	0.977	(5)	0.557	0.796	(6)	0.561	0.783	(4)	0.500	1.000	(1)	0.889
5843 Mega Bank 兆豐商銀	0.532	0.880	(12)	0.626	0.599	(17)	0.667	0.499	(19)	0.555	0.800	(14)	0.694
2834 Taiwan Business Bank 臺企銀	0.534	0.871	(13)	0.581	0.722	(12)	0.595	0.681	(12)	0.527	0.898	(9)	0.793
2893 Shin Kong Bank 新光銀行	0.521	0.920	(8)	0.565	0.769	(10)	0.567	0.762	(5)	0.500	1.000	(1)	0.863
2895 Sunny Bank 陽信商銀	0.528	0.893	(9)	0.564	0.774	(9)	0.569	0.758	(6)	0.525	0.904	(8)	0.832
2845 Far Eastern Bank 遠東銀	0.530	0.888	(10)	0.562	0.779	(7)	0.591	0.693	(11)	0.566	0.766	(17)	0.782
5852 Yuanta Bank 元大銀	0.559	0.790	(16)	0.594	0.682	(14)	0.642	0.558	(17)	0.594	0.685	(19)	0.679
5849 Bank SinoPac 永豐銀行	0.532	0.880	(11)	0.572	0.749	(11)	0.587	0.702	(10)	0.504	0.984	(6)	0.829
5847 E.Sun Bank 玉山銀	0.506	0.976	(6)	0.545	0.834	(4)	0.560	0.784	(3)	0.500	1.000	(1)	0.899
5848 Taishin Bank 台新銀	0.500	1.000	(1)	0.546	0.830	(5)	0.572	0.749	(7)	0.531	0.883	(10)	0.866
5841 CTBT Bank 中信銀	0.500	1.000	(1)	0.524	0.908	(1)	0.545	0.834	(1)	0.500	1.000	(1)	0.935
Mean	0.529	0.894		0.574	0.747		0.595	0.685		0.533	0.881		

Examining the profitability weight values for two successive years in **Table 3**, it becomes evident that approximately 53% to 54% of the resource allocation within Taiwan's banking industry is directed toward the profitability stage. This allocation signifies that, over the long term, banks place greater reliance on achieving profitability in their operations. However, it is essential to note that this heavy emphasis on profitability does not necessarily guarantee the attainment of superior overall operating efficiency.

During the consecutive years of 2020 and 2021, it is noteworthy that none of the banks reached the maximum efficiency score. The ability to discriminate efficiency is

most evident during this period. Specifically, CTBC Bank retained its status as the leader with the highest efficiency scores, registering values of 0.908 in 2020 and 0.843 in 2021. Conversely, on the other end of the spectrum, Changhwa Bank and Mega Bank held the lowest positions in the rankings, recording efficiency scores of merely 0.589 and 0.499, respectively.

4.2. Marketability efficiency analysis

Table 4 presents the empirical findings pertaining to the marketability efficiency of the 19 banks in the period of 2019 and 2022. In 2019, two banks, namely Sunny Bank and E.Sun Bank, occupied the top positions in the ranking, registered scores of 0.937 and 0.898, respectively. However, shifting our focus to the stage efficiency in 2022, it becomes apparent that while Sunny Bank retains as the first, E.Sun Bank falls to the third quarter (ranked 14) in the ranking board. The second position is replaced by Shanghai Bank with the efficiency score equals to 0.869.

Table 4. Marketability efficiency scores and their weights of the 19 Taiwan banks.

Banks	2019			2020			2021			2022			Mean Eff.
	Weight	Eff.		Weight	Eff.		Weight	Eff.		Weight	Eff.		
5858 Bank of Taiwan 臺銀	0.465	0.621	(18)	0.412	0.606	(19)	0.380	0.771	(17	0.460	0.604	(18)	0.651
5857 Land Bank of Taiwan 土銀	0.488	0.601	(19)	0.437	0.674	(18)	0.427	0.753	(19)	0.494	0.604	(19)	0.658
5854 Taiwan Cooperative Bank 合庫	0.438	0.744	(14)	0.394	0.860	(9)	0.372	0.921	(11)	0.437	0.735	(15)	0.815
5844 First Bank 一銀	0.444	0.817	(7)	0.399	0.882	(8)	0.387	0.947	(8)	0.456	0.787	(8)	0.858
5838 Hua Nan Bank 華銀	0.424	0.809	(9)	0.372	0.896	(7)	0.361	0.965	(6)	0.443	0.784	(9)	0.863
2801 Chang Hwa Bank 彰銀	0.436	0.755	(13)	0.371	0.816	(15)	0.342	0.917	(13)	0.421	0.768	(11)	0.814
5876 Shang Hai Bank 上海商銀	0.500	0.798	(10)	0.467	0.853	(12)	0.423	1.000	(1)	0.462	0.869	(2)	0.880
5836 Taipei Fubon Bank 台北富邦銀	0.500	0.709	(16)	0.475	0.719	(17)	0.451	0.757	(18)	0.500	0.670	(17)	0.714
5835 Cathay United Bank 國泰世華	0.494	0.838	(5)	0.443	0.930	(4)	0.439	0.937	(10)	0.500	0.836	(5)	0.885
5843 Mega Bank 兆豐商銀	0.468	0.769	(11)	0.374	0.951	(3)	0.333	1.000	(1)	0.445	0.764	(12)	0.871
2834 Taiwan Business Bank 臺企銀	0.466	0.737	(15)	0.419	0.821	(14)	0.405	0.917	(14)	0.473	0.803	(7)	0.820
2893 Shin Kong Bank 新光銀行	0.479	0.811	(8)	0.435	0.912	(6)	0.433	0.978	(4)	0.500	0.818	(6)	0.880
2895 Sunny Bank 陽信商銀	0.472	0.937	(1)	0.436	0.964	(2)	0.431	0.961	(7)	0.475	1.000	(1)	0.966
2845 Far Eastern Bank 遠東銀	0.470	0.859	(4)	0.438	0.828	(13)	0.409	0.898	(15)	0.434	0.850	(4)	0.859
5852 Yuanta Bank 元大銀	0.441	0.832	(6)	0.406	0.853	(11)	0.358	0.941	(9)	0.406	0.781	(10)	0.852
5849 Bank SinoPac 永豐銀行	0.468	0.706	(17)	0.428	0.776	(16)	0.413	0.868	(16)	0.496	0.733	(16)	0.771
5847 E.Sun Bank 玉山銀	0.494	0.898	(2)	0.455	0.977	(1)	0.440	0.978	(3)	0.500	0.742	(14)	0.899
5848 Taishin Bank 台新銀	0.500	0.767	(12)	0.454	0.854	(10)	0.428	0.919	(12)	0.469	0.755	(13)	0.824
5841 CTBT Bank 中信銀	0.500	0.885	(3)	0.476	0.921	(5)	0.455	0.977	(5)	0.500	0.869	(3)	0.913
Mean	0.471	0.784		0.426	0.847		0.405	0.916		0.467	0.777		

Among these 19 banks, Far Eastern International Bank is the focus of our attention. Worth noting is its foray into digital innovation, exemplified by its pioneering initiative, the Bankee Social, slated to launch Taiwan's inaugural Metaverse branch in 2022. This groundbreaking endeavor empowers members to curate their unique branches in the Metaverse, offering an immersive experience of being a branch manager and community owner. Bankee's Play-to-earn (P2E) strategy caters to the immersive experience and targets a younger demographic, aligning with the themes discussed in the literature (Jung et al., 2020).

Our analysis further reveals fluctuations in the performance of the 19 banks in the second stage of marketability, with an increased trend of efficiency in 2020 and 2021, followed by a decrease in 2022. Shanghai Bank and Taiwan Business Bank notably improved their relative positions in the marketability efficiency rankings in 2022. Notably, more than half of the lower-efficient banks, such as the Bank of Taiwan, Taiwan Cooperative Bank, Hua Nan Bank, and Mega Bank, belong to the public sector. This underscores the public banks' strategic disregard for market-oriented business.

First Bank, as a public institution, emerges as a standout with the highest number of mobile payment users and electronic financial transaction volume among its peers in the public banking sector. While its efficiency and quality improvements have been modest, it has been diligently executing a series of digital transformation initiatives since 2017. To foster consensus and drive innovation, it established a "Digital Strategy Development Group" in 2021, extending its digital transformation efforts toward a more inclusive and sustainable business model, indicative of its adeptness in market business operations.

Analysis of **Figure 1** and **Table 2** reveals that the three primary input variables in the marketability stage encompass revenues (Z1), the number of mobile payment users (Z2), and the volume of electronic financial transactions (Z3), while the outputs include net income (Y1) and earnings per share (Y2). Hence, mobile payment usage emerges as a pivotal factor in the marketability stage of banking. It is anticipated that a higher number of mobile payment users or increased electronic financial transaction volume will lead to higher market efficiency values for competitive banks.

Delving into the banks that exhibited relative improvements in marketability efficiency rankings in 2022, we observe a relative uptick in the user base related to mobile payment variables. Moreover, these banks maintained their performance levels in terms of mobile payment electronic transaction volume, witnessing notable growth in electronic financial transaction volumes. Notably, when examining the net income and earnings per share data, they all posted higher figures in 2022 compared to 20119. This analysis underscores that these banks have effectively harnessed returns by bolstering their market-oriented business activities, as reflected in their improved performance and rankings in marketabilities.

It is discernible that the marketability weights within Taiwan's banking industry range between 45% and 46%. This observation implies that the industry tends to allocate relatively fewer resources to business activities that have the potential to generate higher market value for banks. However, it is imperative to recognize that agile management, grounded in customer-centricity and strategic resource allocation, along with the implementation of an enhanced customer experience service model,

represents specialized paradigms capable of significantly augmenting customer loyalty and engagement.

4.3. Overall efficiency analysis

The overall efficiency measure employed in this study is a composite of weighted individual-stage efficiencies. Additionally, as we transition from the first stage to the second stage, the analysis incorporates intermediate outputs, specifically the number of mobile payment users and the volume of mobile payment electronic financial transactions, to assess the efficiency performance of each stage. The pivotal variables, coupled with the quality of stage efficiency values and the magnitude of weight values, wield a substantial influence on the overall operational performance of banks.

In this part, we conduct an overall efficiency analysis for the period 2019 and 2022. To streamline the presentation, we present the estimated results, as delineated in **Table 5**. The average overall efficiency for the year 2019 stands at 0.840, followed by a decreasing trend in 2020 (0.786) and 2021 (0.775), and finally boosted up again in 2022 (0.830). Notably, the group of underperformed banks, falling below this average threshold, include Bank of Taiwan, Taiwan Land Bank, Taiwan Cooperative Bank, First Bank, Huanan Bank, Changhwa Bank, and Taiwan Business Bank. It's noteworthy that not only are these banks publicly owned, but their relative performance in total efficiency during 2018 was also suboptimal. Upon scrutinizing the individual stage efficiencies and weightings of these banks, it becomes evident that there has been an insufficient adjustment in resource allocation and strategic focus.

CTBC Bank is the only one that achieved a unique overall efficiency score of 1 in the period 2019–2021, before slightly decreasing in 2022 (0.934). It stands as the sole bank among the 19 banks analyzed to attain a total efficiency value of 1 across three consecutive years. Another interesting story is derived from Far Eastern Bank which, in 2016, established a digital financial business group and launched the digital sub-brand, Bankee Community Banking, in 2019. This initiative introduced an innovative business model rooted in the sharing economy, thereby reshaping the traditional one-way relationships between banks and customers and fostering increased competition. It has had three major transformative effects, specifically in terms of data autonomy.

Furthermore, regarding overall operational efficiency, Sunny Bank and Shinkong Bank demonstrated an improved relative performance and ranking of efficiency values in 2022 compared to 2019. In the first stage, profitability efficiency, Sunny Bank consistently maintained modest efficiency scores and ranked in the middle while Shinkong Bank exhibited a great improvement to jump from the middle group to the first tier in 2022. Furthermore, their performance in the second stage, related to marketability also exhibited enhanced relative performance and ranking in 2022 compared to the previous year. Additionally, the two banks posted an average earnings per share of 2.86 yuan over the four years, second only to Shanghai Bank at 3.44 yuan. These banks continue to fortify their market activities, elevate the proficiency of financial professionals, and enhance customer satisfaction. These efforts are palpably reflected in the amplified numbers of mobile payment users and the volume of electronic financial transactions.

Table 5. Overall efficiency scores of the 19 Taiwan banks.

Banks	2019		2020		2021		2022		Mean Eff.
	Eff.	Rank	Eff.	Rank	Eff.	Rank	Eff.	Rank	
5858 Bank of Taiwan 臺銀	0.753	19	0.661	19	0.674	17	0.738	18	0.706
5857 Land Bank of Taiwan 土銀	0.781	15	0.732	15	0.748	13	0.793	13	0.763
5854 Taiwan Cooperative Bank 合庫	0.763	18	0.732	14	0.714	14	0.758	16	0.742
5844 First Bank 一銀	0.807	13	0.751	13	0.753	12	0.815	11	0.782
5838 Hua Nan Bank 華銀	0.768	16	0.705	17	0.710	15	0.791	14	0.743
2801 Chang Hwa Bank 彰銀	0.765	17	0.674	18	0.655	19	0.745	17	0.710
5876 Shang Hai Bank 上海商銀	0.899	5	0.866	3	0.846	5	0.863	6	0.869
5836 Taipei Fubon Bank 台北富邦銀	0.854	9	0.816	8	0.792	8	0.835	9	0.824
5835 Cathay United Bank 國泰世華	0.908	4	0.855	5	0.851	4	0.918	3	0.883
5843 Mega Bank 兆豐商銀	0.828	10	0.731	16	0.666	18	0.784	15	0.752
2834 Taiwan Business Bank 臺企銀	0.809	11	0.764	10	0.776	10	0.853	8	0.800
2893 Shin Kong Bank 新光銀行	0.868	8	0.831	7	0.856	3	0.909	4	0.866
2895 Sunny Bank 陽信商銀	0.914	3	0.857	4	0.845	6	0.950	1	0.891
2845 Far Eastern Bank 遠東銀	0.875	7	0.801	9	0.777	9	0.802	12	0.814
5852 Yuanta Bank 元大銀	0.808	12	0.752	12	0.695	16	0.724	19	0.745
5849 Bank SinoPac 永豐銀行	0.799	14	0.760	11	0.771	11	0.860	7	0.797
5847 E.Sun Bank 玉山銀	0.937	2	0.899	2	0.869	2	0.871	5	0.894
5848 Taishin Bank 台新銀	0.883	6	0.841	6	0.822	7	0.823	10	0.842
5841 CTBT Bank 中信銀	0.943	1	0.914	1	0.899	1	0.934	2	0.923
Mean	0.840		0.786		0.775		0.830		

4.4. Some discussions

The empirical evidence reveals a discernible pattern in the banking sector of Taiwan, where the average profitability stage's weights outweigh the ones of marketability, registering at approximately 0.54 as opposed to 0.42. This observation signifies that Taiwan's banking industry places greater reliance on profitability performance as a key driver of its operational strategies. Concurrently, resource allocation and investment decisions exhibit a conspicuous inclination toward emphasizing performance metrics. The bank's profit-generating activities predominantly encompass operational efficiency and profitability, with relatively less emphasis directed towards activities aimed at enhancing market value, commonly referred to as market capability efficiency. This empirical outcome aligns with the findings reported by Luo (2003), whose research on 245 major banks in the United States yielded congruent results.

As delineated in extant scholarly investigations such as those by Kumbhakar and Wang (2007) and Bardhan (2013), discernible disparities frequently manifest in the operational performance of public banks vis-à-vis private banks. To ascertain and compare the divergence in the operating efficiency of Taiwan's public and private banks under the mobile payment efficiency framework, this study employs the non-parametric Mann-Whitney U-Test. The null hypothesis (H0) posited herein asserts there is no difference between the operating efficiency of Taiwan's public sector banks when compared to private banks when mobile payment activities are considered. To scrutinize this proposition, separate tests are conducted with a focus on overall efficiency, profitability efficiency, and marketability efficiency.

The resulting z-values derived from these tests yield −4.642, −4.116, and −3.341, respectively, all surpassing the critical threshold of 1.96 in absolute magnitude. This compellingly leads to the rejection of the null hypothesis across all three dimensions, signifying that the mobile payment efficiency model exerts a significant divergence on the operational efficiency of public banks at both the individual stage and the aggregate level. Furthermore, the empirical evidence highlights a noteworthy disparity in the operating performance between private and public banks, with private banks exhibiting markedly superior operational efficiency.

Last but not least, our key concern revolves with the contribution of variables representing mobile payment activities. In the research model, these variables serve as both outputs for the profitability and inputs for the marketability stages. By employing the formula $\eta_d^{AB} z_{d0}^{AB} / \sum_{d=1}^{d_{AB}} \eta_d^{AB} z_{d0}^{AB}$, we can compare the relative contributions of these variables with Total revenue (traditional profitability) to the overall efficiency of the system. The result indicates that the contributions of Total revenue, Electronic transaction volume, and No of Users base are 62%, 35%, and 3%, respectively. This outcome aligns with the analysis of the current situation of the non-cash payment sector in Taiwan. Concurrently, it suggests that mobile payment activities have not garnered adequate attention from investors.

5. Conclusions and managerial suggestions

In the preceding era, the burgeoning dependence of contemporary banking on digital technology was an unforeseen trajectory. Institutions lacking robust digital capabilities have gradually witnessed a decline in customer support within the intensely competitive landscape of financial innovation. This shifting paradigm in customer preferences has instigated a direct transformation in banks' operational paradigms (Al-Okaily et al., 2023). Notably, in European and American markets, the ascendancy of "challenger banks" has gained significant traction, compelling traditional banks to intensify their investments in digital infrastructure and services. Conversely, customers increasingly exhibit a pragmatic indifference toward whether their service provider is a conventional bank or a financial technology company; their paramount concern lies in the expeditious accessibility of requisite services via their mobile devices. Consequently, the financial sector has undergone a notable evolution towards enhanced adaptability and sophistication, with mobile technology emerging as an indispensable competence for every financial operator. In this dynamic milieu,

seizing clientele from diverse channels becomes imperative, allowing for the conversion of crises into opportunities and the cultivation of a new industry landscape.

Drawing upon the most recent statistical data from the "Financial Technology Investment and Application in the Financial Industry" survey, released by the Financial Supervisory Commission in August 2022, it is discerned that the total investment by the domestic financial industry in the development of financial technology exhibited a year-on-year decrease of 2.351 billion NTD in 2021. This decline can be primarily attributed to the high base established in 2020, particularly in the realm of pure online banking, leading to a notable contraction in growth, approximating nearly 13%. Nonetheless, the projected investment amount for 2022 has surged to 31.215 billion NTD, signaling a noteworthy estimated annual growth rate of 96.8%. This upward trajectory underscores the substantial emphasis that domestic financial institutions have placed on the realm of financial technology, accentuating its strategic significance within the sector.

Furthermore, it is noteworthy that the collaboration between the domestic financial industry and the financial technology sector exhibited a notable upsurge, with a year-on-year increase of approximately 16% in 2021 as compared to 2020. This collaboration encompasses a spectrum of domains, encompassing information security, big data utilization, artificial intelligence applications, anti-money laundering (AML) measures, Know Your Customer (KYC) protocols, and payment systems, among others.

Despite the widespread application of the DEA approach for evaluating efficiency within the financial sector, it is notable that there remains a scarcity of studies employing this approach to assess the performance of banks in Taiwan. This study, therefore, contributes to the literature of this field by utilizing the Network DEA to explore the practical performance of Taiwan's banking industry in the context of mobile payment integration. Important findings of the research include: (1) there exists a predominant allocation of resources, within Taiwan's banking industry, that is directed towards the profit-generation stage. However, it is discerned that there exists a shortfall in the allocation of resources towards the market-oriented phase, specifically, those activities aimed at augmenting the market value of banks; (2) when mobile payment is incorporated as an intermediary variable within the second stage, it unequivocally enhances the discernment of factors that contribute to inefficiencies within Taiwan's banking industry. This underscores the imperative for Taiwan's financial sector, which may be perceived as somewhat trailing in the global drive for financial innovation and mobile payment services, to redouble its efforts. To rectify the operational inefficiencies plaguing the industry, it is incumbent upon Taiwan's financial sector to bolster its technical proficiency and enhance the penetration rate of mobile payment services, aligning itself more effectively with the evolving dynamics of the global financial landscape; (3) within the cohort of 19 sampled banks, a noteworthy observation emerges, wherein the operational performance of private banks conspicuously surpasses that of public banks across each stage of performance assessment. This discernible divergence underscores a pressing imperative in the context of the ongoing wave of financial reform—the eight prominent banks affiliated with the public sector must intensify their efforts to bridge the performance gap and strive for competitiveness parity with their private sector counterparts.

It is imperative for the Taiwan government to proactively foster a more financially inclusive and amicable milieu, and take concerted action to champion measures aimed at catalyzing the advancement of financial technology. Moreover, the government should wholeheartedly endorse and incentivize collaborative initiatives between the financial and technology sectors. In recent years, Taiwan's banking industry has steadfastly adhered to a corporate ethos rooted in sustainable development and collaborative partnerships, thereby contributing to both societal and environmental well-being. By actively integrating green energy and responsible lending practices with philanthropic endeavors and shareholder engagement, the industry has wielded a constructive influence on the financial landscape. The enhancement of mobile payment services serves as a pivotal conduit towards aligning with the United Nations Sustainable Development Goals (SDGs), implementing Environmental, Social, and Governance (ESG) principles, and catalyzing sustainable consumption patterns.

In addition to the aforementioned contributions, this study has certain limitations. Firstly, concerning the marketability stage, numerous investors are not solely concerned with the bank's growth but also with the attractiveness of its stocks, as indicated by variables such as stock turnover. Incorporating these variables would provide a more precise depiction of the performance of marketability. Furthermore, exploring operational risks as an undesirable output variable of mobile payment activities, such as losses stemming from transaction system errors or resultant legal actions, holds considerable potential for future research endeavors.

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