Chen, Xiang; Fu, Tsu-tan; Juo, Jia-Ching; Yu, Ming-miin

Article

A comparative analysis of profit inefficiency and productivity convergence between Taiwanese and Chinese banks

BRQ Business Research Quarterly

Provided in Cooperation with:
Asociación Científica de Economía y Dirección de Empresas (ACEDE), Madrid

Suggested Citation: Chen, Xiang; Fu, Tsu-tan; Juo, Jia-Ching; Yu, Ming-miin (2020) : A comparative analysis of profit inefficiency and productivity convergence between Taiwanese and Chinese banks, BRQ Business Research Quarterly, ISSN 2340-9436, Sage Publishing, London, Vol. 23, Iss. 3, pp. 193-202, https://doi.org/10.1177/2340944420941439

Article

Business Research Quarterly
2020, Vol. 23(3) 193–202

DOI: 10.1177/2340944420941439
journals.sagepub.com/home/brq
SAGE

A comparative analysis of profit inefficiency and productivity convergence between Taiwanese and Chinese banks

Xiang Chen[1], Tsu-Tan Fu[2], Jia-Ching Juo[3] and Ming-Miin Yu[4]

Abstract

To insure a proper and meaningful productivity assessment of DMUs with different production technologies, this article develops a difference-based profit metafrontier Luenberger productivity indicator. Adopting the proposed model, we empirically measure the profit inefficiency and examine the profit productivity convergence for samples banks consisting of 31 Taiwanese banks and 50 Chinese city banks over 2010–2014. Empirical results show that Chinese banks perform better in profit efficiency than Taiwanese banks. While Chinese banks have better technology in profit creation than Taiwanese banks, the latter may reap much higher profit gain than the former if they can adopt the profit metafrontier. The results of the profit metafrontier Luenberger productivity indicator analysis show that both Chinese and Taiwanese banks have experienced declines in profit productivity. However, the results also indicate a divergence in productivity growth for Chinese city banks and a convergent productivity growth for Taiwanese banks.

JEL CLASSIFICATION: D20, G21, P34

Keywords

Luenberger indicator, metafrontier, profit productivity, bank performance

Introduction

To accommodate a potential measuring problem of the ratio-based Malmquist Productivity Index (MPI) which fails to model the distance function with both input contraction and output expansion, Chambers et al. (1996) develop the difference-based Luenberger productivity indicator (LPI) with the directional distance function. The duality between the directional distance function and the profit function provides the LPI to be a useful mean for performance assessment when profitability is the overall goal of firms. LPI has received much attention recently for various applications (Boussemart et al., 2018; Briec & Kerstens, 2009; Epure et al., 2011; Juo et al., 2015; Lansink et al., 2015; Lin et al., 2017). Briec and Kerstens (2009) extend the Luenberger framework of Chambers et al. (1996) by diagnosing the economic conditions under which infeasibility may occur and exploring solutions. Epure et al. (2011) use LPI to analyze changes in productivity and efficiency of Spanish banks and decompose this indicator into pure efficiency, scale change, and congestion change. Lansink et al. (2015) develop primal and dual versions of the Luenberger productivity growth, depending on the dynamic directional distance function and cost minimization. Lin et al. (2017) also set up a cost-oriented LPI and provide its decomposition. Furthermore, Juo et al. (2015) enhance the profit-oriented LPI by giving a full picture of the sources of productivity change, whereas Boussemart et al. (2018) provide an extended decomposition of LPI on Chinese healthcare sector assessment.

Although LPI has already defined many extensions, to our knowledge, the current versions of LPI still fail to

[1]China Institute of Regulation Research, and China Academy of Financial Research, Zhejiang University of Finance and Economics, Hangzhou, China
[2]Department of Economics, Soochow University, Taipei
[3]Department of International Business, Lunghwa University of Science and Technology, Taoyuan
[4]Department of Transportation Science, National Taiwan Ocean University, Keelung

Corresponding author:
Tsu-Tan Fu, Department of Economics, Soochow University, 100006 Taipei.
Email: tfu@econ.sinica.edu.tw

consider decision-making units' (DMUs') productivity differentials across different groups where they may separately operate under different technologies. A direct comparison may not be valid if DMUs operate under different production technologies (O'Donnell et al., 2008). To make an analogous comparison of efficiency or productivity indices of DMUs across different technology groups, it is necessary to build a common technology frontier, called metafrontier, for all DMUs.

Battese et al. (2004) and O'Donnell et al. (2008) develop the metafrontier production function models that allows for the possibility of technological differences across groups to measure comparable efficiency scores of DMUs among these groups. Such a metafrontier framework has been extended to measure productivity change over time using the ratio-based MPI by studies such as Chen et al. (2009), Oh (2010), Oh and Lee (2010), and Chen and Yang (2011). They are however still subject to the above-mentioned limitation embedded in the ratio-based MPI. To accommodate such limitation under the metafrontier framework, this article attempts to fill this research gap by developing a profit metafrontier LPI and applies the proposed model to assess the performance of profit efficiency and productivity changes on the banking industries of Taiwan and China.

The banking industries in Taiwan and China have different technologies due to their political separation since 1945. With the establishment of the cross-strait financial supervision memorandum of understanding (MOU) and the Economic Cooperation Framework Agreement (ECFA), Taiwanese and Chinese banks now have the opportunity for offering financial services to companies on the other side of the Taiwan Strait. Facing huge market opportunities for investment and financial activities in China, Taiwanese banks are looking to enlarge their scale of operations and taking advantage of cheaper labor costs in China. The incentives for Chinese banks may rest on the good opportunities to adopt a better operating technology as well as the rich experiences of financial development from Taiwan. Mutual benefits are expected if both parties can eliminate market restrictions and collaborate in accessing better production technology and a large-scale financial market (for Taiwan's banks). However, such benefits are unpredictable without extensive information of the operation performance of banks in these two economies. To obtain comparable results of a bank's productivity and efficiency in China and Taiwan, the adoption of the metafrontier framework should work well.

Previous studies have investigated the efficiency and productivity performance between Chinese and Taiwanese banks under the production or cost metafrontier framework. Chen and Yang (2011) apply the meta production frontier to examine the technical efficiency of banks in Taiwan and China, whereas Huang and Fu (2013) develop the cost metafrontier function to compare the cost efficiency and technology gap. Huang et al. (2015) apply the metafrontier cost MPI to assess the dynamic banking performances between China and Taiwan.

Despite profitability is the ultimate goal for most of banks, we find very few profit efficiency studies that compare profit performances across groups or regimes. Mulwa and Emrouznejad (2013) first introduce profit efficiency analysis under the metafrontier framework. Fu et al. (2016) consider risk-based metafrontier profit efficiency model to analyze bank performances in Taiwan and China. While measuring profit efficiency under metafrontier framework, both studies only employ a single-period metafrontier profit model and fail to consider the changes of profit efficiency and productivity over time. Juo et al. (2015) are the first to utilize LPI for measuring the dynamic profit-oriented productivity performance of Taiwanese banks. They combine the Nerlovian profit efficiency measurement with the conventional LPI and give a full picture of the source of profit productivity change. However, unless their model can be extended to a metafrontier framework, it is otherwise inadequate for comparing firms' performance from production groups with different production technologies.

Profit inefficiency is an indicator to measure manager's ability to adopt the best input–output bundle for profit maximization given input–output prices faced by DMUs. The profit loss due to profit inefficiency is defined as the difference between maximized profit and observed profit. The input–output bundle of the profit maximization may be a benchmark for less profit inefficiency DMUs to emulate if they face similar prices as the benchmark DMU does. It is a general interest to decompose profit inefficiency into technical inefficiency and allocative inefficiency. The directional vector using current input–output for projecting observed point on production frontier can help identify an appropriate measure of technical inefficiency. The allocative inefficiency could be biased without an appropriate technical inefficiency measure. Since the input–output bundle of a DMU varies over time, it is also necessary to assure the directional vector to be time variant for inducing appropriate technical and allocative inefficiencies over time. The drawback of adopting time-invariant directional vector has also been raised by previous studies. Balk (2018) criticized that the time-invariant directional vector used in Juo et al. (2015) resulted in a failure to provide a meaningful interpretation to price effect, a component of productivity decomposition. Aparicio et al. (2012) pointed out that a time-invariant directional vector would cause an inappropriate measure of technical efficiency. A time-variant directional vector is thus necessary for an appropriate measurement of the profit-oriented LPI and its productivity decomposition.

In this study, we therefore extend the profit-oriented LPI of Juo et al. (2015) into a metafrontier framework with a time-variant directional vector. This newly developed metafrontier profit-oriented LPI measures the profit

productivity and efficiency performance across banks in Taiwan and China. The measures for the gaps in productivity help us examine the convergence between the group profit frontier and the profit metafrontier. These analyses have not been expressively accounted for in the LPI literature. We hence empirically apply the proposed profit metafrontier LPI to measure the profit efficiency and productivity of 31 Taiwanese banks and 50 Chinese city banks in the period 2010–2014.

Compared to the previous literature, we make three contributions to the application of profit analysis. First, we develop a new metafrontier profit-oriented LPI. Our proposed model not only considers a profit-oriented productivity comparison between two groups due to group-specific heterogeneity but also combines the intertemporal changes in productivity, thus offering a supplement to the studies of Juo et al. (2015) and Fu et al. (2016). In addition, our proposed indicator is distinct from that of Juo et al. (2015) on the assumption of using a direction vector. We propose a time-variant direction vector which avoids the problems mentioned by Balk (2018) and Aparicio et al. (2013). Second, the proposed LPI model successfully accommodates the problem and limitation embedded in the ratio-based MPI under the metafrontier framework. Third, this study is the first to empirically analyze the profit-oriented efficiency and productivity changes of Taiwanese and Chinese city banks by the proposed method.

The remainder of the article is organized as follows. "Methodology" section defines the methodology used to measure the profit inefficiency and profit LPI under the group frontier and metafrontier technologies. "Data and variables" section lists the definitions of variables and data statistics. "Empirical results" section is the empirical results and discussion. The conclusion follows in the "Conclusion" section.

Methodology

Group-specific technologies, meta-technologies, and profit inefficiency

This study considers the panel data of the hth ($h=1, 2, \ldots, H$) production group—for example, of a country or an industry. Assume that DMUs at period t use the input vector $x^t (x^t \in R_+^N)$ to produce an output vector $y^t (y^t \in R_+^M)$. This study defines its production technology set at period t for the hth group as follow: $S_h^t = \{(x^t, y^t) : x^t \text{ can produce } y^t\}$, where S_h^t, is assumed to be convex and closed.

The directional distance function (DDF) is defined by

$$\overrightarrow{D_h^t}(x^t, y^t; -g_x^t, g_y^t) = sup\left\{\beta : (x^t - \beta g_x^t, y^t + \beta g_y^t) \in S_h^t\right\} \quad (1)$$

where the directional vector $g^t = (-g_x^t + g_y^t)$, $g_x^t \in R_+^N$, and $g_y^t \in R_+^M$ denotes that this function shifts by simultaneously contracting inputs and expanding outputs, so as to reach the production frontier. Thus, $\overrightarrow{D_h^t}(x^t, y^t; -g_x^t, g_y^t)$ also represents the degree of technical inefficiency (TI_h^t).

The profit function is defined for the technology S_h^t as

$$\pi_h^t(p^t, w^t) = sup\left\{p^t y - w^t x : (x, y) \in S_h^t\right\} \quad (2)$$

Equation (2) implies that maximum profit is greater or equal to the observed profit

$$\pi_h^t(p^t, w^t) \geq p^t y^t - w^t x^t \forall (x^t, y^t) \in S_h^t$$

The relationship of profit inefficiency measure πl_h^t and technical inefficiency measure (Tl_h^t) can be expressed as

$$\begin{aligned} \pi l_h^t &= \frac{\pi_h^t(p^t, w^t) - (p^t y^t - w^t x^t)}{p^t g_y^t + w^t g_x^t} \\ &\geq \overrightarrow{D_h^t}(x^t, y^t; -g_x^t, g_y^t) \end{aligned} \quad (3)$$

We note that profit inefficiency measure, πl_h^t, or the difference in maximal profit and observed profit, is normalized by the sum of $(p^t g_y^t + w^t g_x^t)$, following the definition of Nerlovian profit efficiency (Chambers et al., 1998). The right-hand side of equation (3), $\overrightarrow{D_h^t}(x^t, y^t; -g_x^t, g_y^t)$, measures technical inefficiency. The gap in the inequality equation (3) reflects the residual inefficiency of profit, and so, we define allocative inefficiency (Al_h^t) as

$$\begin{aligned} Al_h^t &= \frac{\pi_h^t(p^t, w^t) - (p^t y^t - w^t x^t)}{p^t g_y^t + w^t g_x^t} \\ &\quad - \overrightarrow{D_h^t}(x^t, y^t; -g_x^t, g_y^t) \end{aligned} \quad (4)$$

Rearranging equation (4), profit inefficiency can be decomposed into two sources as

$$\pi l_h^t = Tl_h^t + Al_h^t \quad (5)$$

From equation (5), it can be seen that profit inefficiency is a summation of technical inefficiency and allocative inefficiency. The former (Tl_h^t) measures production of less outputs yielded from excessive inputs. The latter (Al_h^t) results from the inappropriate output–input mix in light of their given prices.

The meta-technology at period t can be defined as the convex hull of group technologies. This study assumes that all members in each group operate under a common potential frontier, the meta-technology set, that is, $S_*^t = convex\ hull\ (S_1^t \cup S_2^t \cup S_3^t \cup \cdots \cup S_h^t)$.

Under the meta-technology, we similarly define DDF along the direction $g^t = (-g_x^t, +g_y^t)$ as

$$\begin{aligned} &\overrightarrow{D_*^t}(x^t, y^t; -g_x^t, g_y^t) \\ &= sup\left\{\gamma : (x^t - \gamma g_x^t, y^t + \gamma g_y^t) \in S_*^t\right\} \end{aligned} \quad (6)$$

When a DMU operates under the production metafrontier, its profit function at period t is

$$\pi_*^t(p^t, w^t) = sup\left\{ p^t y^t - w^t x^t : (x, y) \in S_*^t \right\} \quad (7)$$

The meta-Nerlovian profit inefficiency measure is defined as

$$\pi I_*^t = \frac{\pi_*^t(p^t, w^t) - (p^t y^t - w^t x^t)}{p^t g_y^t + w^t g_x^t} \quad (8)$$

Similarly, we can decompose meta-profit inefficiency πI_*^t into meta-technical inefficiency and meta-allocative inefficiency as follows

$$\pi I_*^t = TI_*^t + AI_*^t \quad (9)$$

The difference between the meta-profit inefficiency πI_*^t and the group-specific profit inefficiency πI_h^t is defined the profit inefficiency gap (πI_h^G)

$$\pi I_h^G = \pi I_*^t - \pi I_h^t \quad (10)$$

The profit inefficiency gap, πI_h^G, measures the incremental degree of potential profit inefficiency if a DMU operates under the metafrontier instead of its group-specific frontier. By comparing equation (8) to (3), we also can define πI_h^G as the difference in DMUs' maximum profits between operating under the metafrontier and under the group frontier. The positive (negative) value of πI_h^G indicates that the maximum profit under the profit metafrontier is higher (lower) than that under the group-specific profit frontier. Therefore, the higher the value of πI_h^G a DMU has, the more profit it could gain if it operates using the metafrontier instead of the group frontier.

The profit inefficiency gap πI_h^G can be further decomposed into technical inefficiency gap (TI_h^G) and allocative inefficiency gap (AI_h^G)

$$\begin{aligned} \pi I_h^G &= \pi I_*^t - \pi I_h^t = (TI_*^t + AI_*^t) - (TI_h^t + AI_h^t) \\ &= (TI_*^t - TI_h^t) + (AI_*^t - AI_h^t) = TI_h^G + AI_h^G \end{aligned} \quad (11)$$

Here, TI_h^G and AI_h^G denote the respective technical inefficiency gap and allocative inefficiency gap, while TI_h^G measures the distance of the meta-technology frontier to the group technology frontier, and its value is always positive since the group technology frontiers are enveloped by the meta-technology frontier. The AI_h^G allocative inefficiency gap measures the difference between the meta-allocative inefficiency and the group-specific allocative inefficiency. It is also regarded as DMU's pure maximum profit difference between the metafrontier and group frontier after excluding the profit gain attributed to the technology adoption of the metafrontier over the group frontier. The value of AI_h^G could be positive, negative, or zero.

Group-specific technologies, meta-technologies, and profit LPI

The LPI introduced by Chambers et al. (1996) is used to evaluate a difference-based productivity change. This indicator is defined and calculated by the quantity distance function.

This study defines the profit-oriented LPI between periods t and $t+1$ for the hth group as

$$\pi L_h^{t,t+1} = \frac{1}{2}\left\{ \left[\frac{\pi_h^t(p^t, w^t) - (p^t y^t - w^t x^t)}{p^t g_y^t + w^t g_x^t} - \frac{\pi_h^t(p^t, w^t) - (p^t y^{t+1} - w^t x^{t+1})}{p^t g_y^{t+1} + w^t g_x^{t+1}} \right] + \left[\frac{\pi_h^{t+1}(p^{t+1}, w^{t+1}) - (p^{t+1} y^t - w^{t+1} x^t)}{p^{t+1} g_y^t + w^{t+1} g_x^t} - \frac{\pi_h^{t+1}(p^{t+1}, w^{t+1}) - (p^{t+1} y^{t+1} - w^{t+1} x^{t+1})}{p^{t+1} g_y^{t+1} + w^{t+1} g_x^{t+1}} \right] \right\} \quad (12)$$

Here, we assume the directional vector to be time-variant $g^t = (-g_x^t, +g_y^t) = (-x_{hj}^t, y_{hj}^t)$,[1] and $g^t \neq g^{t+1}$. Thus, the value of the production size (directional vector times prices of inputs and outputs) will be different over time. This profit LPI implies productivity progress, regress, or constant if its value is positive, negative, or zero, respectively.

Under the metafrontier technology, the meta-profit LPI ($\pi L_*^{t,t+1}$) can be similarly defined as the group-specific profit LPI, except that period t's (also period $t+1$'s) group-specific profit functions ($\pi_h^t(p^t, w^t), \pi_h^{t+1}(p^{t+1}, w^{t+1})$) are replaced by meta-profit functions ($\pi_*^t(p^t, w^t)$, $\pi_*^{t+1}(p^{t+1}, w^{t+1})$). Therefore, the meta-profit productivity, referred to as meta-technology, can be defined the same as those equations for the group-specific profit LPI.

For a DMU, we define the profit LPI gap of the hth group-specific frontier to the metafrontier as the difference ratio for the profit productivity change between the meta-technology ($\pi L_*^{t,t+1}$) and its own chosen group-specific technology ($\pi L_*^{t,t+1}$) of equation (12)

$$\pi L_h^G = \pi L_*^{t,t+1} - \pi L_h^{t,t+1} \quad (13)$$

If $\pi L_*^{t,t+1} > \pi L_h^{t,t+1}$ ($\pi L_*^{t,t+1} < \pi L_h^{t,t+1}$), then profit productivity growth between periods t and $t+1$ is faster (slower) under the meta-technology than that under the group-specific technology, which means a divergence (convergence) of the group-specific frontier from (toward) the meta-profit frontier. We define this gap πL_h^G as the catch-up index. This catch-up index indicates the difference in the speed of productivity change between group-specific frontiers and the meta frontier for different banking industries over time. It implies convergence if $\pi L_h^G < 0$, divergence if

Table 1. Variable specification.

Variable	Name	Definition
Input variables		
x1	Financial funds	Including deposits and borrowed funds (millions of US$)
x2	Labor	Number of employees (persons)
Quasi-fixed input variable		
f1	Physical capital	Net amount of fixed assets (millions of US$)
Output variables		
y1	Investments	Including financial assets, securities, and equity investments (millions of US$)
y2	Loans	Including loans and discounts (millions of US$)
Input price variables		
w1	Price of funds	Interest expenses divided by total deposits (US$ million/ US$ million)
w2	Price of labor	Personal expenses divided by number of employees (unit: US$ million per person)
Output price variables		
p1	Price of investments	Revenue from investments divided by investment (US$ million/ US$ million)
p2	Price of loans	Revenue from loans divided by loans (US$ million/ US$ million)

$\pi L_h^G > 0$, and a constant growth gap if $\pi L_h^G = 0$. The catch-up index is important information to examine whether the productivity of a banking industry can outperform the productivity of another banking industry in the future.

Suppose banking industry A has a negative catch-up index value for the last t few years. We thus expect the productivity of banks in banking industry A is getting closer (convergent) to the metafrontier over time. On the contrary, banking industry B exhibits divergence in consecutive years, implying that these banks' productivity is moving away over time from the metafrontier. We may conclude that the productivity growth of banks in banking industry A will outperform those banks in banking industry B in the future, even though the current productivity level of the former is lower than the latter.

It should be noted that the group-specific and metafrontier profit LPI can be decomposed into components of technical efficiency change, allocative efficiency change, technical change, and price effect. In our empirical estimation. We also adopt the short-run variable profit function, instead of the long-run profit function.[2]

Data and variables

The sample data consist of 50 Chinese city commercial banks and 31 Taiwanese banks over the period 2010–2014. We do not include those state-owned and joint-stock Chinese banks, because these banks are operating across provinces in China and have a much larger scale of operations than Taiwanese banks. Chinese city banks operate mainly within a province, whereas Taiwanese banks provide service in Taiwan. Since Taiwan's geographical size is similar to the size of a province in China, a performance comparison using samples of Chinese city banks and Taiwanese banks can avoid the problem of great scale diversity and may provide meaningful managerial implications.

This study follows the intermediation approach for the specification of inputs and outputs. It assumes that the bank collects deposits to transform them with labor and capital into loans and other earning assets. Following Fu et al. (2016) and Berger and Humphrey (1997), this study considers two outputs: financial investments (y1) and total loans (y2). The investments are defined as other earning assets, including financial assets, securities, and equity investments. The corresponding unit price of the investments (p1) is the ratio of the investments' revenue to the total investments. Total loans consist of all types of loans issued that generate a given amount of interest income. The corresponding unit price of loans (p2) is the ratio of the raised amounts of interest income to the total loans.

This study specifies two inputs and one quasi-fixed input. The input vector includes financial funds (x1) and labor (x2). The quasi-fixed input (f1) is physical capital, which is the net amount of fixed assets. Financial funds (x1) are defined as deposits and borrowed funds. This input always accounts for the highest percentage of total costs in a bank, but it also generates interest and other financial expenses. Thus, the corresponding unit price (w1) is calculated as the ratio of financial expenses to financial funds. Labor (x2) is defined as the number of employees, while the corresponding unit price (w2) is calculated as a ratio of personal expenses to the total number of employees. Table 1 defines all the variables.

Table 2 presents summary statistics of the sample banks. The column for the annual growth rate in Table 2 clearly shows that both Taiwanese and Chinese city banks experience positive growth in outputs and inputs, whereas the growth in China outperforms that in Taiwan during the sample period. The output structure between the two groups presents a significant difference, as the value share of investment to loans is about 1:1 in China compared to that of 1:3 in Taiwan. It implies that there are different strategies on funding allocation between banks in Taiwan

Table 2. Summary statistics of inputs and outputs, 2010–2014.

Variables	2010		2011		2012		2013		2014		Annual growth rate
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*
y1: investments (US$ million)											
Taiwan	6,267	6,907	5,838	6,627	6,595	6,989	7,013	7,144	7,299	7,303	3.05%
China	5,504	8,234	6,925	10,183	9,408	12,799	12,320	16,101	14,920	19,794	19.94%
y2: loans (US$ million)											
Taiwan	19,081	17,787	19,682	18,127	21,619	19,602	21,838	19,477	22,473	19,744	3.27%
China	6,577	9,045	8,318	11,095	10,342	13,596	12,459	16,042	14,683	9,967	16.06%
x1: financial funds (US$ million)											
Taiwan	25,733	23,410	26,038	23,141	28,687	25,299	29,478	26,500	30,233	26,358	3.22%
China	11,176	13,966	13,593	16,238	16,687	19,392	20,474	23,013	23,340	26,436	14.73%
x2: labor (persons)											
Taiwan	3,879	2,450	3,958	2,507	3,969	2,529	4,037	2,657	4,104	2,667	1.13%
China	2,210	1,699	2,494	1,849	2,862	2,041	3,272	2,261	3,603	2,389	9.78%
f1: physical capital (US$ million)											
Taiwan	420	490	432	581	456	620	443	594	442	585	1.05%
China	101	107	126	131	173	179	212	221	247	253	17.79%
p1: price of investments (US$ million/ US$ million)											
Taiwan	0.0334	0.0551	0.0303	0.0395	0.0215	0.0169	0.0167	0.0130	0.0151	0.0090	–15.88%
China	0.0150	0.0147	0.0151	0.0147	0.0177	0.0188	0.0162	0.0285	0.0203	0.0250	6.05%
p2: price of loans (US$ million/ US$ million)											
Taiwan	0.0206	0.0040	0.0229	0.0042	0.0242	0.0044	0.0238	0.0042	0.0237	0.0035	2.80%
China	0.0805	0.0137	0.1082	0.0280	0.1199	0.0364	0.1178	0.0321	0.1250	0.0324	8.80%
w1: price of financial funds (US$ million/ US$ million)											
Taiwan	0.0057	0.0011	0.0071	0.0012	0.0077	0.0013	0.0073	0.0012	0.0076	0.0012	5.75%
China	0.0154	0.0041	0.0255	0.0085	0.0316	0.0091	0.0317	0.0088	0.0378	0.0111	17.96%
w2: price of labor (US$ million per person)											
Taiwan	0.0384	0.0098	0.0383	0.0096	0.0415	0.0093	0.0427	0.0106	0.0440	0.0113	2.71%
China	0.0256	0.0095	0.0327	0.0119	0.0419	0.0433	0.0377	0.0109	0.0411	0.0120	9.46%

and China. Moreover, a five to six times higher output growth rate in China than in Taiwan also indicates faster growing financial demand in China, which may attract Taiwanese bankers to invest in China.

The price of investments (p1), representing the return on investment, shows that the price of investment in Taiwan was higher than that in China in 2010, but it decreased over time at a rate of –15.88%. While such a price in China showed a low positive level of growth in 2010–2013, it was catching up with Taiwanese banks in 2014. As for the price of loans (p2), representing the return to loans, Table 2 shows that this price has been more than four times higher in China versus that in Taiwan during the sample period, which implies a much higher return rate for making loans in China. Such a difference in prices of outputs could induce different portfolio decisions for banks in Taiwan and China.

For input prices, the price of financial funds (w1) in Taiwan is much cheaper than that in China, whereas the price of labor (w2) in Taiwan is relatively higher than that in China. The prices of both inputs are also found to be increasing over time, and a relative higher growth rate can be seen especially in China. The difference in relative prices in inputs between Taiwan and China provides strong incentives for banks in both places to operate on the opposite side of the Taiwan Strait under the recently signed financial cooperation agreement.

In sum, the high growth of outputs in China and the difference in output structure and prices between two economies induce mutual incentives for financial cooperation. Furthermore, the vast difference in the relative price ratio and growth rate of inputs for banks in Taiwan and China may result in different impacts of price changes on bank efficiency and productivity.

Empirical results

Analysis of meta-profit and group-specific profit inefficiencies

Results of meta-profit inefficiency and its decompositions. To consider the different production environments of banks in China and Taiwan, we employ the proposed profit meta-frontier framework to compare bank performances across

Table 3. Meta-profit inefficiency and its decomposition.

Year	China					Taiwan				
	πI^*	=	TI^*	+	AI^*	πI^*	=	TI^*	+	AI^*
2010	0.3355		0.0871		0.2483	0.6476		0.0638		0.5838
2011	0.3212		0.0659		0.2552	0.7458		0.0632		0.6826
2012	0.2757		0.0665		0.2092	0.6373		0.0505		0.5868
2013	0.2973		0.0747		0.2226	0.6259		0.0511		0.5748
2014	0.2999		0.1019		0.1980	0.4695		0.0652		0.4042
Mean	0.3059[a]		0.0792[a]		0.2267[a]	0.6252[a]		0.0588[a]		0.5665[a]

[a]Significant difference at the 5% level between Taiwanese and Chinese banks by the Wilcoxon-Mann–Whitney test.

the Taiwan Strait. Table 3 presents the results of meta-profit inefficiency and its decompositions for Chinese and Taiwanese banking industries over the period 2010–2014. The meta-profit inefficiency (πI^*) is defined as the profit difference between maximum profit and observed profit to a normalized vector, $p^t g_y^t + w^t g_x^t$ (representing a bank's production size), as in equation (8). Table 3 indicates that the mean meta-profit inefficiency (πI^*) of Taiwanese banks (0.6252) is about two times higher than that of Chinese banks (0.3059). It implies that Chinese banks are on average closer to the maximal profit benchmark than Taiwanese banks, and thus they are better in profit efficiency.

Profit inefficiency consists of two components: technical inefficiency TI^* and allocative inefficiency AI^*. Table 3 shows that the technical inefficiency (TI^*) score for banks in China and Taiwan is, respectively, 0.0792 and 0.0588, implying that the profit loss due to technical inefficiency is negligible compared to that from allocative inefficiencies (AI^*) score, showing 0.2267 and 0.5665 for banks in China and Taiwan, respectively. Such a huge difference between allocative inefficiency and technical inefficiency has been found in each year for banks in Taiwan and China. Therefore, we may conclude that profit inefficiency can be mostly attributed to allocative inefficiency for the sample banks. In addition, the relatively high mean allocative inefficiency of banks in Taiwan as compared to that of banks in China also indicates a better allocation of output–input mix of Chinese city banks over Taiwanese banks. The differences in πI^*, TI^*, and AI^* between Taiwanese banks and Chinese banks are found to be significantly different at the 5% level by the Wilcoxon-Mann–Whitney test.

Results of group-specific profit inefficiency and its decompositions. For a comparison of profit inefficiency between group-specific and metafrontier frameworks, we conduct group-specific profit inefficiency analysis. Table 4 summarizes the results of group-specific profit inefficiency and its decomposition. We find that the mean group-specific profit inefficiency (πI) is 0.1973 for Taiwanese banks and 0.2986 for Chinese banks, denoting that Taiwanese banks are a bit closer to their own Taiwan group–specific profit frontier than Chinese banks to the China group–specific profit frontier.

Table 4. Group-specific profit inefficiency and its decomposition.

Year	China				Taiwan			
	πI	= TI	+ AI		πI	= TI	+ AI	
2010	0.3332	0.0608	0.2724		0.2677	0.0584	0.2093	
2011	0.3199	0.0464	0.2734		0.1907	0.0369	0.1539	
2012	0.2720	0.0478	0.2241		0.1755	0.0300	0.1455	
2013	0.2665	0.0517	0.2149		0.1846	0.0254	0.1593	
2014	0.3013	0.0852	0.2161		0.1679	0.0249	0.1430	
Mean	0.2986	0.0584	0.2402		0.1973	0.0351	0.1622	

It should be also noted that the values of profit inefficiency for Taiwanese banks estimated from group frontier (0.1973 in Table 4) and metafrontier (0.6252 in Table 3) are found to be significantly different. Such discrepancy in profit inefficiency may reveal a fact that Taiwanese banks operate much better under current Taiwan specific technology than under a potential metafrontier technology, given current input and output prices. On the contrary, the difference in values of profit inefficiency for Chinese banks estimated from group frontier (0.3059 in Table 4) and metafrontier (0.2986 in Table 3) are found to be insignificant. The Chinese banks thus perform no difference in profit efficiency between under China group specific technology and under the metafrontier technology.

Allocative inefficiency (AI) shows similar pattern as that in profit inefficiency. The negligible values of technical inefficiency (TI) between banks in Taiwan and banks in China also indicate that the group-specific profit inefficiency may be mainly attributed to their allocative inefficiency.

Results of the profit inefficiency gap and its decompositions. As indicated in equation (10) earlier, πI_h^G can be regarded as the difference in DMUs' maximum profits between operating under the metafrontier and operating under the group frontier. A higher value in πI_h^G implies a better

Table 5. Profit inefficiency and its components' gaps.

Year	China					Taiwan				
	πI^G	=	TI^G	+	AI^G	πI^G	=	TI^G	+	AI^G
2010	0.0023		0.0264		−0.0241	0.3799		0.0054		0.3745
2011	0.0013		0.0195		−0.0182	0.5550		0.0263		0.5287
2012	0.0038		0.0187		−0.0149	0.4617		0.0204		0.4413
2013	0.0307		0.0230		0.0077	0.4413		0.0257		0.4156
2014	−0.0015		0.0167		−0.0181	0.3016		0.0404		0.2612
Mean	0.0073[a]		0.0209		−0.0135[a]	0.4279[a]		0.0236		0.4043[a]

[a]Significant difference at the 5% level between Taiwanese and Chinese banks by the Wilcoxon-Mann–Whitney test.

Table 6. Group-specific profit LPI πL, metafrontier profit LPI πL^* and their gap (πL^G).

Year	China					Taiwan				
	πL^G	=	πL^*	−	πL	πL^G	=	πL^*	−	πL
2010−2011	0.0081		−0.0765		−0.0846	−0.184		−0.109		0.075
2011−2012	0.0257		−0.1018		−0.1275	−0.0589		−0.0589		0
2012−2013	0.0465		−0.0336		−0.0801	−0.0798		−0.0752		0.0046
2013−2014	0.1271		−0.046		−0.1731	−0.0491		−0.0512		−0.0021
Mean	0.0518[a]		−0.0645[a]		−0.1163	−0.093[a]		−0.0736[a]		0.0194

[a]Significant difference at the 5% level between Taiwanese and Chinese banks by the Wilcoxon-Mann–Whitney test.

potential profit increment for a bank to adopt the metafrontier technology. On the contrary, a bank with a low value in πI_h^G would imply there is low potential profit increment for it to undertake the metafrontier technology, but it can instead undertake the group frontier technology.

Table 5 shows that the mean profit inefficiency gap πI_h^G is 0.4279 in Taiwanese banks and 0.0073 in Chinese banks. A very low gap value for the Chinese banks means that the profit gain will be negligible for Chinese banks to operate under the metafrontier technology since their gaps between group and meta-profit frontiers are very small. On the contrary, Taiwanese banks have a relatively high value (0.4279) of πI_h^G, which implies that Taiwanese banks can potentially increase their profit up to 43% of their production size if they operate under the metafrontier rather than under the current Taiwanese group frontier. Therefore, Taiwanese banks can reap much profit gain if they can operate using the profit metafrontier, whereas such profit gain to Chinese banks may be very small.

Table 5 also shows that the allocative inefficiency gap (AI^G) for Taiwanese banks (M=0.4043) contributes mostly to profit inefficiency (M=0.4279). Therefore, manager's ability of finding a better input–output mix to maximize profit (given input and output prices) under metafrontier technology is crucial and the key to the profit maximization for Taiwanese banks. The Wilcoxon-Mann–Whitney test results on the profit inefficiency gap and the allocative inefficiency gap between Taiwanese banks and Chinese banks are significantly different at the 5% level.

Results of the metafrontier profit LPI and gap. The metafrontier profit LPI (πL^*)expresses the change in profit productivity over time for banks in Taiwan and China given a common profit frontier. As in previous sections, the metafrontier profit Luenberger productivity is defined as growth, decline, and constant if $\pi L^* > 0$, <0, and $=0$, respectively. Table 6 lists the mean values of πL^* for Chinese banks (−0.0645) and for the Taiwanese banks (−0.0736) during the sample period 2010–2014. We see that, given a profit metafrontier, both Chinese and Taiwanese banks have experienced profit productivity declines, and the average declining rate of profit productivity for Chinese banks is significantly lower than that of Taiwanese banks as the Wilcoxon-Mann–Whitney test presents.

As shown in equation (13), the profit Luenberger productivity gap is defined as $\pi L_h^G = \pi L_*^{t,t+1} - \pi L_h^{t,t+1}$. If $\pi L_*^{t,t+1} < \pi L_h^{t,t+1}, \pi L^G < 0$, then a DMU's profit productivity growth between periods t and $t+1$ under the meta-technology is higher than that under the group-specific technology. The negative value of πL^G implies a convergence of the profit group-specific frontier toward the profit metafrontier. Thus, (πL^G) can be regarded as the catch-up index. Having consecutive negative (πL^G) values, a DMU's profit group frontier catches up with the profit metafrontier over time, which implies that the DMUs in such a group have better ability to reap the benefit of adopting the meta-profit frontier. On the contrary, the positive value of πL^G implies a divergence of the profit group-specific frontier from the profit meta frontier. The profit productivity growth rate

from the group frontier is however lower than that from the metafrontier.

Table 6 summarizes the results of the profit LPI gap (πL^G). The mean values of the profit productivity gaps (πL^G) are 0.0518 for Chinese banks and −0.0930 for Taiwanese banks. The positive values of πL^G for Chinese banks denote divergence in their productivity along the China profit frontier over time, while the Taiwanese banks with negative values of πL^G show their productivity growth is catching up with the meta-profit frontier over time.

Overall, the results present an opposite pattern of productivity growth for Taiwanese and Chinese banks.

Conclusion

To accommodate the potential measuring problem of the ratio-based MPI which fails to model the distance function with both input contraction and output expansion, Chambers et al. (1996) develop the difference-based LPI with a directional distance function. Despite LPI having received much attention with various applications, previous research on LPI still fails to insure a proper and meaningful productivity assessment for DMUs with different production technologies. In this article, we thus adopt the metafrontier framework of Battese et al. (2004) and O'Donnell et al. (2008) and extend the profit-oriented LPI of Juo et al. (2015) from a group-specific frontier to a metafrontier version. The proposed model helps us to measure the profit productivity and efficiency performances across banks in Taiwan and China, which are operating under different production technologies. We also examine the degree of convergence between the profit group frontier and profit metafrontier by comparing those profit LPI results from the group specific and metafrontier technologies for Taiwanese and Chinese city banks.

The empirical evidence herein finds that relative to Taiwanese banks, Chinese banks are characterized as having higher profit efficiency and higher allocative efficiency under meta-technology. Allocative inefficiency plays a major contribution to profit inefficiency. Given a smaller profit inefficiency gap for Chinese banks than that for Taiwanese banks, we conclude that the Chinese banks have better technology in profit creation than Taiwanese banks during the sample period. However, Taiwanese banks may reap much profit gain if they can reach the profit metafrontier, whereas such profit gains for Chinese banks may be very small. Therefore, the Taiwan government should promote Taiwanese banks to take advantage of the financial cooperation between Taiwan and China.

The results of the profit metafrontier LPI analysis show that both Chinese and Taiwanese banks have experienced declines in profit productivity. However, results of different patterns in profit productivity dynamics also indicate a divergence in productivity growth for Chinese city banks and a convergent productivity growth for Taiwanese banks.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Notes

1. Given a time-invariant direction vector g, the profit Luenberger productivity indicator ($\pi L^{t,t+1}$) is an empirical Bennet quantity indicator. Under our time-variant direction vector setting, $\pi L^{t,t+1}$ is not equal to the Bennet quantity indicator. We thank a referee for raising the problem of the time-invariant direction vector.
2. The LPI decomposition and its empirical implementation are available upon request.

References

Aparicio, J., Pastor, J. T., & Ray, S. C. (2013). An overall measure of technical inefficiency at the firm and at the industry level: The 'lost profit on outlay'. *European Journal of Operational Research*, *226*, 154–162.

Balk, B. M. (2018). Profit-oriented productivity change: A comment. *Omega*, *78*, 176–178.

Battese, G. E., Rao, D. S. P., & O'Donnell, C. J. (2004). A metafrontier production function for estimation of technical efficiencies and technology gaps for firms operating under different technologies. *Journal of Productivity Analysis*, *21*, 91–103.

Berger, A. N., & Humphrey, D. B. (1997). Efficiency of financial institutions: International survey and directions for future research. *European Journal of Operational Research*, *98*, 175–212.

Boussemart, J. P., Ferrier, G. D., Leleu, H., & Shen, Z. (2018). An expanded decomposition of the Luenberger productivity indicator with an application to the Chinese healthcare sector. *Omega*, *91*, Article 102010. http://dx.doi.org/10.1016/j.omega.2018.11.01

Briec, W., & Kerstens, K. (2009). The Luenberger productivity indicator: An economic specification leading to infeasibilities. *Economic Modelling*, *26*, 597–600.

Chambers, R. G., Chung, Y., & Färe, R. (1998). Profit directional distance functions and Nerlovian efficiency. *Journal of Optimization Theory and Applications*, *98*, 351–364.

Chambers, R. G., Färe, R., & Grosskopf, S. (1996). Productivity growth in APEC countries. *Pacific Economic Review*, *1*, 181–190.

Chen, K. H., Huang, Y. J., & Yang, C. H. (2009). Analysis of regional productivity growth in china: A generalized metafrontier MPI approach. *China Economic Review*, *20*(4), 777–792.

Chen, K. H., & Yang, H. Y. (2011). A cross-country comparison of productivity growth using the generalised metafrontier Malmquist index: With application to banking industries in Taiwan and China. *Journal of Productivity Analysis*, *35*, 197–212.

Epure, M., Kerstens, K., & Diego, P. (2011). Bank productivity and performance groups: A decomposition approach based upon the Luenberger productivity indicator. *European Journal of Operational Research*, *211*, 630–641.

Fu, T. T., Juo, J. C., & Chiang, H. C. (2016). Risk-based decompositions of the meta profit efficiency of Taiwanese and Chinese banks. *Omega*, *62*, 34–46.

Huang, M. Y., & Fu, T. T. (2013). An examination of the cost efficiency of banks in Taiwan and China using the metafrontier cost function. *Journal of Productivity Analysis*, *40*, 387–406.

Huang, M. Y., Juo, J. C., & Fu, T. T. (2015). Metafrontier cost Malmquist productivity index: An application to Taiwanese and Chinese commercial banks. *Journal of Productivity Analysis*, *44*, 321–335.

Juo, J. C., Fu, T. T., & Yu, M. M. (2015). Profit-oriented productivity change. *Omega*, *57*, 176–187.

Lansink, A. O., Stefanou, S., & Serra, T. (2015). Primal and dual dynamic Luenberger productivity indicators. *European Journal of Operational Research*, *241*, 555–563.

Lin, Y. H., Fu, T. T., & Chen, C. L. (2017). Non-radial cost Luenberger indicator. *European Journal of Operational Research*, *256*, 629–639.

Mulwa, R., & Emrouznejad, A. (2013). Measuring productive efficiency using Nerlovian profit efficiency indicator and metafrontier analysis. *Operational Research*, *13*, 271–287.

O'Donnell, C. J., Rao, D. S. P., & Battese, G. E. (2008). Metafrontier frameworks for the study of firm-level efficiencies and technology ratios. *Empirical Economics*, *34*, 231–255.

Oh, D.-h. (2010). A metafrontier approach for measuring an environmentally sensitive productivity growth index. *Energy Economics*, *32*, 146–157.

Oh, D.-h., & Lee, J. (2010). A metafrontier approach for measuring Malmquist productivity index. *Empirical Economic*, *38*, 47–64.