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Abstract

This paper examines the relationships between competition, efficiency and stability in the banking systems of four East Asian countries (China, Hong Kong, Malaysia and Vietnam) over 2004–2014. The results support the traditional competition–fragility view and suggest that an increase in competition may result in a decrease in stability. Similarly, credit risk, bank size and market concentration may positively affect bank stability. By contrast, banks with higher liquidity risk and revenue diversification may become less stable. Empirical analysis suggests that banking sector stability was adversely affected by the global financial crisis. Listed banks may be less stable than their non-listed peers. The macroeconomic environment (measured in terms of inflation and GDP growth) also affects bank stability. Additionally, some important policy implications with respect to improving bank stability are recommended.

Keywords: Bank competition; bank efficiency; bank stability; bank fragility; East Asian banking systems, Sub-sampling bootstrapped DEA approaches, *Z*-score.

1. Introduction

Banks have to cope with many potential challenges and threats to their stability. The financial collapse of 2008 resulted in financial risk and even fragility for many banks. Since the 2008–2009 global financial crisis (GFC), there have been heightened concerns about the financial stability of all financial institutions. Due to the intricate relationship between financial stability and macroeconomic stability, financial stability is not ensured even in a stable macroeconomic environment. Financial stability analysis, therefore, cannot be ignored. The banking sector is the most important element of a financial system and acts as the financial backbone of a country's economy. Insolvency in the banking sector may impact the overall economy due to its influence on governments, corporations, and stakeholders, including employees, managers, shareholders, creditors and lenders. Thus, an awareness of the factors that determine stability is of essential interest to both researchers and policy makers.

In numerous studies on bank stability, one of factors examined as a determinant of stability is competition. However, there still exist two opposing views on whether competition influences bank stability: (i) the competition–fragility and (ii) the competition–stability hypotheses. According to the former viewpoint, there is a trade-off between bank stability and competition (Allen & Gale, 2004; Dam et al.,2015; Keeley, 1990; Nguyen et al., 2012; Turk Ariss, 2010). In contrast, the latter view suggests that competition enhances stability in the banking industry (Beck et al., 2010; Boyd & De Nicolló, 2005; Brown & Dinç, 2011; Demirgüç-Kunt & Huizinga, 2013; Fiordelisi & Mare, 2014; Noman et al., 2017; Soedarmono et al., 2013; Stern & Feldman, 2004).

In recent years, another issue which has attracted the attention of researchers is the impact of efficiency on stability. Academic research on this relationship is still in its infancy and has provided mixed evidence. The positive link between efficiency and stability is indicated by Berger & DeYoung (1997), Fiordelisi et al. (2011), Kwan & Eisenbeis (1997), Lin et al. (2005), Zhang et al. (2013). By contrast, other studies by Altunbas et al. (2007) and Tan & Floros (2013) argue that there is a trade-off between these factors.

The previous studies, however, primarily concentrated on the impact of either competition or efficiency on stability instead of the simultaneous effects of both competition and efficiency on stability. Additionally, almost all of these studies use a sample of banks in the United States and European countries rather than other regions. The recent crisis; however, has heightened concerns for both researchers and policy makers about stability in East Asian financial markets (Adams, 2008). East Asian banking markets have experienced significant changes during the period from the late 1980s to the early 21st century. Regional banking systems have dramatically restructured by focusing on closures, mergers and acquisitions, and capital injections from official and private, foreign and domestic sources (Adams, 2008). In addition, banks have expanded investment banking-type activities and household and real estate lending activities (Adams, 2008). Financial liberalization from the 1980s was expected to improve both bank competition and efficiency in regional banking industries (Adams, 2008; Moshirian, 2008; Nguyen et al., 2012; Soedarmono et al., 2013). Despite rapid development due to the financial liberalization, East Asian banks underwent the extreme 1997–98 financial crisis leading to massive bankruptcies (Rajan, 2007). Not only that, the latest global crisis in 2008–09 significantly affected these markets, particularly the large banks (Ree, 2011). Both financial and global crises have affected the East Asian region and the regional banking industry to a great degree. Very little academic research, however, has paid attention to the impacts of both competition and efficiency on stability in this region. Therefore, this study investigates simultaneously the effects of competition and efficiency on stability using a sample of commercial banks in four East Asian countries (China, Hong Kong, Malaysia and Vietnam) over the period 2004–2014.

This paper makes several contributions to the existing literature. *First*, it attempts to address the issue of efficiency of East Asia's commercial banks using both the Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA) approaches. *Second*, it uses the sub-sampling bootstrap method to correct the bias of DEA cost efficiency scores. *Third*, this research extends the literature on the effect of banking efficiency on stability by considering the context of the East Asian banking industry, especially using direct measures of bank stability instead of bank risk, and cost efficiency instead of bank performance, as used in most previous studies. *Fourth*, this is the first study that examines the effect of both competition and efficiency on the stability of East Asian banks employing various alternative methods to measure cost efficiency, competition, and bank financial stability to check the robustness of the empirical results. *Fifth*, by covering the 2008 GFC in our sample, this study also assesses the impact of the GFC on bank stability.

The rest of this paper is organized as follows. Section 2 reviews the literature on the relationship between competition, efficiency and stability in the banking sector. Data and methodology are presented in Section 3. Section 4 shows the empirical results on estimated competition levels, efficiency and bank stability scores of the East Asian banking systems with an in-depth discussion about the relationship between these factors. Finally, Section 5 provides a conclusion and some policy implications.

2. Literature review

2.1. Bank competition and stability

2.1.1. The competition–fragility view versus the competition–stability view

In the literature on the competition–stability relationship, there are two contrasting views: the competition–fragility and competition–stability hypotheses. The traditional competition–fragility view is that stronger competition in the banking sector leads to higher risks. The more competitive that markets become, the less monopoly rents banks earn and the more risks banks take due to an increase in asset risk, and some decreases in profit, capital ratios and charter values. Thus, banks are less able to withstand strong shocks of demand or supply (Allen & Gale, 2004; Keeley, 1990). Petersen and Rajan (1995) found that market power can help a bank to solve problems of asymmetric information and develop lending relationships with other firms.

Alternatively, the competition–stability view has been supported by both recent theoretical and empirical evidence (Fiordelisi & Mare, 2014). Based on the Too-Big-To-Fail or Too-Important-To-Fail views, large or important banks often gain government safety net subsidies, which may induce moral hazard and boost these banks' risk-taking behavior, and consequently cause financial fragility (Beck et al., 2010; Brown & Dinç, 2011; Demirgüç-Kunt & Huizinga, 2013; Stern & Feldman, 2004). When banks have greater market power, they may face insolvency more frequently due to incurring monitoring costs and taking aggregate risk or hazardous loan portfolios (Caminal & Matutes, 2002). Financing obstacles are heightened when sector concentration is higher (Beck et al., 2004), and this negatively affects bank stability.

Nevertheless, some academic studies provide evidence of complex relationships between competition and stability (De Nicoló et al., 2004; Fu et al., 2014; Uhde & Heimeshoff, 2009). Caminal and Matutes (2002) indicated a complex relationship between market power and banking failures. Their results showed that banks with more market power have a higher probability of failure when their borrowers face a moral hazard problem. However, project choices depending on market structure may result in bank failure. Therefore, their findings supported an ambiguous actual association between market power and financial fragility. Using a sample of Latin American banks, Tabak et al. (2012) found a non-linear change in bank risk-taking behavior under varying levels of competition: less risk-taking behavior under both high and low competition levels, and more risk-taking behavior under average competition. Their findings showed that larger banks are less vulnerable in a competitive market. Kick and Prieto (2015) indicated different relationships between bank competition and bank risk when using different measures of competition. Market power measured by (in)efficiency-adjusted Lerner indices is negatively associated with bank distress; however, an increase in bank competition tends to reduce bank risk when market share and the Boone indicator[1] are used. Jeon and Lim (2013) explored how differences in the bank competition–stability nexus depend on bank characteristics. The relationship between competition and stability is non-linear for commercial banks but positive for mutual savings banks. Berger et al. (2009) argued that market power can reduce aggregate risk, but bank concentration can lead to more loan portfolio risk. Competition and concentration may encourage stability or fragility concurrently (Berger et al., 2009; Liu et al., 2012). Some studies, such as those of Martinez-Miera & Repullo (2010), Jimenez et al. (2013) and Liu et al. (2013), suggested that a U-shaped relationship exists between competition and stability in the banking industry. In a highly concentrated market, more competition enhances stability; however, high competition may lead to fragility in a competitive banking sector (Liu et al., 2013).

2.1.2. Empirical results on the relationship between competition and stability

Recent studies have paid more attention to the relationship between competition and stability in developing or emerging countries (Turk Ariss, 2010; Agoraki et al., 2011; Beck et al., 2013; Hope et al., 2013; Fungáčová & Weill, 2013; Pak & Nurmakhanova, 2013; Amidu & Wolfe, 2013; Tabak et al., 2015; González et al.,2017; Kouki & Al-Nasser, 2017; Kabir & Worthington, 2017). Findings on the competition–stability relationship are mixed for the Asian banking systems. Liu et al. (2012) showed that higher competition decreases bank risk-taking behavior in four South East Asian countries from 1998 to 2008. They also found that

[1]A measure of the intensity of competition was introduced by Boone (2008) and is calculated as the elasticity of profits to marginal costs.

competition and concentration can occur together and impact synchronously on the stability in the same way. Soedarmono et al. (2011) also support the competition–stability view for 12 Asian banking systems in the post-1997 crisis. Soedarmono et al. (2013) found that banks with higher market power may be more risk-taking and face greater insolvency risk. Using two-step system GMM and both direct and indirect measures of stability, Noman et al. (2017) tested the effects of competition on bank stability in the ASEAN-5 countries over the 1990–2014 period and found that competition enhances bank stability. Louati and Boujelbene (2015) indicated that more competitive Islamic banks become more stable. However, Nguyen et al. (2012) concluded that monopoly banks in South East Asia are more stable if they diversify their income structure. Fu et al. (2014) showed a negative association between pricing power and individual bank risk for 14 Asia Pacific banking systems over 2003–2010. Tan and Anchor (2017) showed mixed relationships between bank competition and stability in China by providing evidence that higher competition is positively related to credit risk, liquidity risk and capital risk, but is negatively related to insolvency risk.

2.2. Bank efficiency and bank stability

The academic literature on the relationship between efficiency and stability in the banking industry is still in its infancy. Over the last few decades, the majority of studies have assessed the relationship between efficiency and stability in developed countries, especially in the US and Europe (Altunbas et al., 2007; Berger & DeYoung, 1997; Brissimis et al., 2008; Fiordelisi et al., 2011; Kwan & Eisenbeis, 1997).

Berger and DeYoung (1997) investigated the inter-temporal links among problem loans, cost efficiency, and capital in the US banking system during the period from 1985 to 1994 using Granger-causality techniques. Their results showed two directions for these relationships. Firstly, greater nonperforming loans precede decreases in measured cost efficiency, supporting the bad-luck hypothesis that the extra costs for nonperforming loan administration decrease measured cost efficiency. By contrast, lower cost efficiency precedes increases in nonperforming loans, consistent with the bad-management hypothesis in both cost efficiency and loan portfolio. Kwan and Eisenbeis (1997) examined the relationship between credit risk-taking and operating efficiency using a simultaneous equation framework and found that inefficiency has a positive impact on risk-taking. These findings provided evidence to support the moral hazard hypothesis that banks with poor performance are more vulnerable to risk-taking than strong performers. Using a sample of European banks, Williams (2004) investigated the inter-temporal links among loan loss provision, bank efficiency and capitalization for savings banks over the period 1990–1998; for this, they employed the Granger causality approach suggested in the study of Berger and DeYoung (1997). The results indicated a positive relationship between loan loss provision and bank efficiency.

Altunbas et al. (2007) concluded that inefficient banks seem to take less risk and hold more capital in European countries over 1992–2000. Also, in the context of European banks, Fiordelisi et al. (2011) suggested that decreases in bank cost efficiency and revenue efficiency precede an increase in bank risk. They also found that improvements in bank efficiency cause a lower probability of default. Deelchand and Padgett (2009) suggested that inefficient Japanese cooperative banks appear to take on more risk and have higher capital.

In recent years, a few empirical studies have examined the efficiency-risk relationship in developing and emerging economies; however, these studies primarily consider the impact of risk on efficiency. Tan and Floros (2013) suggested that risk is positively and significantly related to technical efficiency and pure technical efficiency for the Chinese banking system over 2003–2009. Hou et al. (2014) used a two-stage semi-parametric data envelopment analysis to measure efficiency and found that risk-taking is positively related to technical efficiency in China. Miah and Sharmeen (2015) employed the Seemingly Unrelated Regressions (SUR) method to examine the relationship between capital, risk and efficiency for two kinds of banks in Bangladesh (Islamic and conventional banks) from 2001 to 2011. They found the bank efficiency-risk relationship to be statistically significant only for conventional banks. The findings indicated a bidirectional negative relationship between risk and efficiency for conventional banks. Hence, inefficient conventional banks assume more risk and banks with more risks become less efficient.

Some recent studies provide mixed evidence on the efficiency–stability nexus. By using a large sample of banks in ten newly acceded EU countries over 1994–2005, Brissimis et al. (2008) found a trade-off between liquidity risk and bank efficiency, whereas credit risk has a negative impact on efficiency. Zhang et al. (2013) found that efficiency is negatively impacted by credit risk, market risk, and overall risk in four emerging countries over 2003–2010. Nevertheless, bank efficiency is positively related to liquidity risk, thus suggesting that there is a trade-off between efficiency and liquidity risk. Chan et al. (2014) employed a Tobit model to analyze the impacts of bank risks on bank cost and profit efficiencies for seven East Asian nations over 2001–2008. Their findings suggested that more stable banks may have lower profit efficiency whereas higher liquidity risk may cause lower cost efficiency. Luo et al. (2016) investigated whether financial openness affects both bank risk and profit efficiency directly or via efficiency or risk across 140 countries over 1999–2011 and concluded that banks with lower risk and more stability are more profit efficient.

2.3. The relationship between competition, efficiency and stability in banking systems

Very few empirical studies have examined the simultaneous impact of both bank competition and bank efficiency on bank soundness. However, a few recent studies investigate the effect of competition and risk taking on efficiency or the impact of bank risk and efficiency on competition.

Investigating a sample of European banks from 1995–2005, Schaeck and Čihák (2014) first used the Boone indicator to measure competition and causality tests for examining the relationship between bank competition and bank efficiency. The results showed that competition improves profit efficiency. Then, the authors analyzed the role of bank efficiency in the transmission from bank competition to bank stability; the findings provided evidence to support the idea that competition positively affects bank risk via bank efficiency that is consistent with the findings of Schaeck and Cihák (2010).

Kasman and Carvallo (2014) used the Granger causality technique in dynamic panels to examine the dynamic relationships among bank efficiency, financial stability, and competition in fifteen Latin American banking systems over 2001–2008. Their findings indicated that increases in competition levels precede increases in financial stability when the model's revenue efficiency is being considered, thus providing evidence to support the "competition–stability" view. When cost efficiency is being considered, causality running from competition to financial stability is also positive; however, this finding is significant for Ordinary least squares (OLS) or fixed effect estimators and turns insignificant for GMM estimations. Higher revenue efficiency significantly Granger-causes lower financial stability but causality running from cost efficiency to stability is less robust.

Zhang et al. (2013) use an indirect measure of competition (e.g. market concentration) for investigating the impact of market concentration and risk taking on technical efficiency in China, Russia, Brazil and India over 2003–2010. Their findings supported the "quiet life" hypothesis that proposes a negative relationship between market concentration and bank efficiency. Moreover, the results suggested that lower bank risk taking is associated with higher bank efficiency.

Delis et al. (2017) have raised the issue of controlling for bank risk in measuring efficiency. They note that excluding risk biases estimates of efficiency. Koetter (2008) analyses how risk preference affects the measurement of efficiency, concluding that the chosen proxy for bank risk is related to the more traditional measures of risk such as credit and liquidity risk as used in the present study. As well as controlling for bank-specific measures of risk, it has been suggested that, in a cross-country context, country-level attributes need to be controlled for in the estimation of DEA frontiers. Here, we estimate efficiency scores by country, rather than cross-country but, in the regression analyses, we do control for country-level attributes[2] including industry-specific and macroeconomic measures.

3. Methodology and data

3.1. Methodology

3.1.1. Measuring bank efficiency: SFA, DEA, and Sub-sampling bootstrapped DEA approaches

For a robustness check of the results, both the stochastic frontier analysis (SFA) and Data Envelopment Analysis (DEA) approaches were employed to measure bank efficiency. We measure cost efficiency using the SFA model of Battese and Coelli (1995) that allows analysis of the effects of explanatory variables on inefficiency, in order to explain the differences in the inefficiency effects among banks (details are outlined in Appendix A).

DEA approach

DEA is a nonparametric linear programming (LP) technique that permits evaluation of the relative efficiency of decision-making units (DMUs) without imposing a priori weights on the inputs and outputs. In solving such an LP problem simultaneously for a set of DMUs, weightings are chosen that maximize the efficiency score of each DMU relative to the best-performing peer or peers.

[2] There is an extensive literature on the effects of the regulatory environment on both bank efficiency and stability (for example, see the following recent studies: (Hermes and Meesters, 2015); (Chan and Karim, 2015); (Triki et al., 2017); (Fratzscher et al., 2016); Shaddady and Moore, 2019); Noman et al;. 2018)) but this is not the focus of our study.

Charnes et al. (1978) proposed the DEA-CCR model, which imposes constant returns to scale (CRS). The CRS assumption would be appropriate only if all banks in the sample were operating at their optimal scales, which is a very stringent condition. The DEA-BCC model of Banker, Charnes and Cooper (1984) extends the DEA-CCR model by allowing variable returns to scale (VRS). Following Banker et al. (1984) and Fare et al. (1985), this study uses a VRS cost minimization DEA model for calculating cost efficiency (CE) as follows:

$$\min_{z,x_i} w_{i0} x_{i0}^*$$

Subject to

$$\sum_{k=1}^{K} z_k y_{jk} - y_{j0} \geq 0, \qquad j = 1, 2, ..., m$$

$$\sum_{k=1}^{K} z_k x_{ik} - x_{i0}^* \leq 0, \qquad i = 1, 2, ..., n \qquad (1)$$

$$\sum_{k=1}^{K} z_k = 1$$

$$z_k \geq 0, \qquad k = 1, 2, ..., K$$

where

k: the number of the banks ($k = 1, \ldots, K$)

x_{ik}: i^{th} input of bank k ($i = 1, \ldots, n$)

x_{i0}^*: the cost minimizing vector of input quantities for the evaluated bank

w_{i0}: a vector of the given input prices

w_{ik}: i^{th} input price of k^{th} bank

y_{jk}: j^{th} output of bank k ($j = 1, \ldots, m$)

y_{j0}: the vector of output levels

z: the intensity vector.

In the DEA model, the variables used for outputs, inputs and input prices are the same as those of the SFA model. The outputs are total loans and other earning assets. The inputs are total deposits (x_1), total physical capital (x_2) and labor (x_3) (see Table A.1).

The cost efficiency (CE) of the k^{th} bank is the ratio of the minimum cost to the actual cost or observed cost:

$$CE_k = \frac{\sum_{i=1}^{n} w_{ik} x_{ik}^*}{\sum_{i=1}^{n} w_{ik} x_{ik}} \qquad (2)$$

Sub-sampling bootstrapped DEA approach

DEA requires neither the specification of a functional form nor assumptions related to the distribution of an inefficiency term, as does SFA, since it ignores random error. This may cause bias in efficiency estimates. Thus, bootstrap methods are commonly used to solve this problem. In this study, the sub-sampling bootstrap method was used to correct the bias of Fare et al. (1985) cost efficiency scores as the sub-sampling bootstrap is the best available method and is consistent in the DEA context (Kneip et al., 2008; Simar & Wilson, 2008). Following Algorithm #1 proposed by Kneip et al. (2008), the study modified the sub-sampling bootstrap algorithm for the cost efficiency. Then, the modified algorithm was programmed by using MATLAB as follows:

[1] Cost efficiency scores (CE_k) for bank k were estimated by using the original sample S_K (y_k, x_k, w_k) with $k = 1,\ldots, K$.

[2] A bootstrap sample was generated of size L: $S_L^*\left(y_k^*, x_k^*, w_k^*\right)$ with $k = 1,\ldots, L$ where L observations were randomly drawn (without replacement) from the original sample S_K. The ad hoc rule of thumb was applied to choose L, with L = integer ($K^{2/3}$).

[3] The DEA estimator in Equation 4 was applied to construct bootstrap estimates of cost efficiency for bootstrap sample S_L^*.

[4] The steps [2]-[3] were repeated B times to obtain $CE_{k,b}^*$ with $b = 1,\ldots, B$. This study used B = 2000.

[5] Using the methodology developed by Simar and Wilson (2008), a bootstrap bias estimate of cost efficiency was calculated as follows:

$$Bias_B\left(CE_k\right) = \left(\frac{L}{K}\right)^{\frac{2}{m+n+1}} \left[\frac{1}{B}\sum_{b=1}^{B} CE_{k,b}^* - CE_k\right]$$

A bias-corrected estimator of the efficiency score, $CE_{k,Bias\text{-}corrected} = CE_k - Bias_B(CE_k)\left(\frac{L}{K}\right)^{\frac{2}{m+n+1}}$ was used to correct for the influences of different sample sizes between the original sample, S_K, and bootstrap samples, S_L^*.

3.1.2. Measuring bank competition

We employed the Lerner index approach (Lerner, 1934) to measure competition among banks. This approach is useful as it does not assume the competition-concentration trade-off or imply competition based on concentration, as does the structural approach; thus it provides a better and more direct proxy of competitive behavior (Weill, 2013).

The conventional Lerner index

The conventional Lerner index (L_{CON}) is given as:

$$L_{CON\,kt} = \frac{P_{kt} - MC_{kt}}{P_{kt}} \quad (3)$$

The price (P_{kt}) is defined as average revenue of bank k at year t, which is calculated as the ratio of total revenue to total assets. Total revenue is the sum of total profit before tax (TP) and total costs (TC). Marginal cost (MC_{kt}) of bank k at year t is estimated on the basis of a translog cost function (as explained in Appendix B).

The efficiency-adjusted Lerner index

Unlike the conventional Lerner index, the efficiency-adjusted Lerner index can account for endogeneity bias via simultaneous estimation of both market power degree and efficiency from a single structural model. To consider possible cost inefficiencies of banks, frontier estimates of TC ($\widehat{TC}$) and TP ($\widehat{TP}$) are calculated using the model of Battese and Coelli (1995). The Efficiency-adjusted Lerner index (L_{EFF}) is calculated as follows:

$$L_{EFF\,kt} = \frac{\left(\frac{\widehat{TP}_{kt}}{y_{kt}} + \frac{\widehat{TC}_{kt}}{y_{kt}}\right) - \widehat{MC}_{kt}}{\frac{\widehat{TP}_{kt}}{y_{kt}} + \frac{\widehat{TC}_{kt}}{y_{kt}}} \quad (4)$$

where y_{kt} is total assets of bank k at year t. Both frontier estimates of total cost $\left(\widehat{TC}_{kt}\right)$ and marginal cost $\left(\widehat{MC}_{kt}\right)$ are derived from the translog cost function (Eq. (B.1)). Frontier estimates of total profit ($\widehat{TP}$) are estimated from the alternative profit function that is similar to the cost function in Eq. (B.1); however, *TC* is replaced by total profit before tax (*TP*) as a dependent variable and the error term (ε) is equal to $v - u$.

The funding-adjusted Lerner index

The drawback of the traditional Lerner index is the calculation of the marginal cost may contain some form of monopoly power derived in deposit markets due to the ability to increase funds at low cost (Maudos & De Guevara, 2007; Turk Ariss, 2010). To avoid this drawback, the study used the Funding-adjusted Lerner index (L_{FUND}) which is known as a "clean" proxy of pricing:

$$L_{FUND\,kt} = \frac{\left(\frac{\hat{TP}_{kt}}{y_{kt}} + \frac{\hat{TC}_{kt}}{y_{kt}}\right) - \hat{MC}_{FUND\,kt}}{\frac{\hat{TP}_{kt}}{y_{kt}} + \frac{\hat{TC}_{kt}}{y_{kt}}} \tag{5}$$

The translog cost function to estimate the marginal cost ($\widehat{MC}_{FUND}$) and total cost ($\widehat{TC}$) is shown in Eq. (B.3).

3.1.3. Measuring bank stability

The study measured bank stability using the Z-score, introduced by Boyd and Graham (1986). The score reflects the probability of bank failure because it evaluates overall stability at the bank level. The Z-score deals simultaneously with the influences of profitability, leverage and volatility of return on the stability or the failure probability of an individual bank. Higher Z-scores indicate more bank stability.

The formulas of the Z-scores are:

$$Z - score_{ROA\,kt} = \frac{ROA_{kt} + EA_{kt}}{\sigma_{ROA\,k}} \tag{6}$$

$$Z - score_{ROE\,kt} = \frac{ROE_{kt} + EA_{kt}}{\sigma_{ROE\,k}} \tag{7}$$

where *Z-score*$_{ROA}$, *Z-score*$_{ROE}$: Z-score based on return on average assets and Z-score based on return on average equity, respectively. ROA_{kt} (ROE_{kt}) is return on average assets (return on average equity) of bank k at year t, EA_{kt} is the ratio of the equity over total assets, and σ_{ROA} and σ_{ROE} are the standard deviations of ROA and ROE, respectively.

The Z-score was calculated using a three-year rolling window to compute the mean value of ROA (ROE) at a specific year t. ROA (ROE) at year t were calculated as the mean over 3 years including the present t year and the prior 2 years for an individual bank. $EA_{k,t}$ is equity on total assets of bank k at year t, and σ_{ROA} (σ_{ROE}) is the standard deviation of ROA (ROE) of bank k over the sample period.

3.1.4. The relationship between bank competition, efficiency and stability

To examine the relationship between competition, efficiency and bank stability in East Asian countries, dynamic panel-data models were used:

$$STA_{k,j,t} = f\,(STA_{k,j,t-1}, COM_{k,j,t}, EFF_{k,j,t}, \textit{bank-specific characteristics}_{k,j,t}, \\ \textit{industry-specific characteristics}_{j,t}, \textit{macroeconomic environments}_{j,t}) \qquad (8)$$

where the subscripts k, j and t, respectively, denote the bank, the country and time.

The dependent variable (STA), bank stability, is measured by $Z\text{-}score_{ROA}$ or $Z\text{-}score_{ROE}$. COM is competition measured by conventional Lerner (L_{CON}), efficiency-adjusted Lerner (L_{EFF}) or funding-adjusted Lerner (L_{FUND}). EFF stands for cost efficiency scores, which are estimated by the SFA or subsampling bootstrapped DEA approaches. Bank-specific characteristics, the industry-specific characteristics, and macroeconomic measures are defined in Table 1.

--- insert Table 1 about here ---

Recent empirical research further clarifies the problem of endogeneity in the relationship between competition and bank stability (Berger et al., 2009; Schaeck et al., 2009; Uhde & Heimeshoff, 2009). Following Beck, De Jonghe, et al. (2013) and Anginer et al. (2014), the cost-income ratio, loan growth, and the lagged Lerner index were employed as instrumental variables for Lerner indices. GMM, a generic method developed by Hansen (1982), uses moment conditions to estimate parameters of statistical models. GMM has been widely used in semi-parametric models which have finite-dimensional parameters of interest without the assumption of the distribution function of data. The advantages of the GMM estimator are that it is consistent, asymptotically normally distributed and efficient. In addition, it can avoid the problems of heteroscedasticity and autocorrelation, and deal well with potential endogeneity issues (Greene, 2012). The Arellano-Bond (Arellano & Bond, 1991) and the Arellano-Bover/Blundell-Bond (Arellano & Bover, 1995; Blundell & Bond, 1998) estimators are generalized methods of moment estimators widely used to estimate dynamic panel-data models. The Arellano-Bond estimation, known as the *difference GMM*, eliminates the fixed effect from the model by transforming the regressors of the equation into first differences. On the other hand, the Arellano-Bover/Blundell-Bond estimator, called the *system GMM*, forms a system of two equations – the original and the transformed equation. A system GMM procedure augments the Arellano-Bond technique by adding an assumption that there is no correlation between first differences of instrumental variables and the fixed effects of the model (Roodman, 2009). This assumption can increase the number of instruments and thus can significantly improve the efficiency of the GMM estimator. As a result, the system GMM estimator is more efficient than the difference GMM estimator. In this study, the system GMM estimator for dynamic unbalanced panel-data models was employed to deal with possible endogeneity problems of Lerner indices, heteroscedasticity, and autocorrelation problems.

In order to check whether the instruments are exogenous, the Sargan/Hansen tests of over-identifying restrictions have been applied to test the null hypothesis that instruments are exogenous. The Difference-in-Hansen tests of exogeneity of instrument subsets are also reported; these, known as the *C statistic*, are employed to test whether the instruments used for the equations are exogenous or not. In addition, this study included the performance of the Arellano-Bond technique tests for first and second order serial correlation in the residuals, with the null hypothesis that there is no serial correlation.

3.2. Data

The data were derived from the Bankscope Fitch-IBCA database, which consists of the annual financial statements of individual banks. Financial information was converted to US dollars and was inflation-adjusted, as necessary, to 2004 as base year. Data on the listing status of banks were collected from the Stock Exchanges in each studied country. The macroeconomic data, growth of gross domestic product (GDP Growth) and inflation rate were sourced from the International Financial Statistics database (IFS) of the International Monetary Fund.

After excluding banks that had (a) missing data in more than two consecutive years, (b) observations with negative or zero values for inputs and/or input prices in the DEA and SFA models and (c) missing ROA or ROE values, the sample comprised an unbalanced panel of 1040 observations from 99 commercial banks in East Asia. The countries included in the sample then, were China (25 banks), Hong Kong (23 banks), Malaysia (22 banks) and Vietnam (29 banks).

Table 2 reports the summary statistics of the variables included in the study sample. Bank-level variables are averaged by bank, whereas the country-level variables are averaged by country for the 2004–2014 period.[3]

--- insert Table 2 about here ---

4. Empirical results

4.1. Estimation results for competition, cost efficiency, and stability

Table 3 shows the average estimates for three kinds of Lerner indices. The efficiency- and funding-adjusted Lerner indices are much greater than the conventional Lerner indices for all countries. Hence, using three Lerner specifications may tackle the conventional Lerner indices' underestimates for the degree of market power. The average estimates of cost efficiency by country are shown in Table 3. Using SFA efficiency scores, the results suggest that banks were operating close to their efficiency frontier. The efficiency scores are highest for Vietnam (0.9460), followed by China (0.9424), Hong Kong (0.8987) and Malaysia (0.7823). The average efficiency scores by the subsampling bootstrapped DEA approach seem to be smaller than those by the DEA approach by 0.03 to 0.07 approximately. In comparison with the SFA approach, the subsampling bootstrapped DEA approach provided lower efficiency scores by around 0.14 to 0.19. However, Spearman's rank order correlation coefficient between these two approaches is 0.4671 ($p < 0.001$) suggesting that they are moderately consistent in their rankings. The results are consistent when indicating that the estimated averaged efficiency scores by the SFA and DEA approaches were highest for Vietnam, followed by China, Hong Kong and Malaysia.

[3] Unfortunately, more recent data is not currently available.

--- insert Table 3 about here ---

The average estimates of $Z\text{-}score_{ROA}$ are higher than those of $Z\text{-}score_{ROE}$ for all selected countries. Malaysia had the highest $Z\text{-}score_{ROA}$ on average (41.3236), followed by Hong Kong (33.1442), China (25.5661) and Vietnam (22.0533). For $Z\text{-}score_{ROE}$, the order of countries changes. The banking system in Hong Kong had the highest $Z\text{-}score_{ROE}$ on average (7.1602). Next came, Malaysia and China, which achieved lower scores of 7.1013 and 5.6508, respectively. Similarly, both the $Z\text{-}score_{ROA}$ and $Z\text{-}score_{ROE}$ of the banking system in Vietnam was the lowest (4.3736). These results suggest that banking systems in Malaysia and Hong Kong had the highest stability whereas the Vietnamese banking system seems to have been the least stable.

4.2. The influence of efficiency and competition on bank stability

We employed three tests including the Sargan/Hansen tests, the “Difference-in-Hansen” tests, and the Arellano-Bond technique tests. The results of these tests consistently show that the tests cannot reject the null hypothesis. The Sargan/Hansen tests of over-identifying restrictions cannot reject the null hypothesis that instruments are exogenous. Similarly, the “Difference-in-Hansen” tests of exogeneity of instrument subsets cannot reject the null hypothesis. The Arellano-Bond technique tests for first and second order serial correlation in the residuals with the null hypothesis that there is no serial correlation. The tests cannot reject the null hypotheses for second order serial correlation.

The banking literature shows that competition and efficiency are closely related to each other (e.g., see Schaeck and Cihák, 2014). Thus, in order to assess multicollinearity between competition and efficiency, we use variance inflation factors (VIF) in the regression models. All VIFs are under 2, so the multicollinearity is not a serious problem.

In Tables 4 to 7, the estimated results from six variants of the dynamic panel-data model in Equation 8 are given. To investigate the effect of competition on stability, Models 1 and 2 use the conventional Lerner index, Models 3 and 4 use the efficiency-adjusted Lerner index while Models 5 and 6 use the funding-adjusted Lerner index. Odd-numbered models use the Herfindahl Hirschman index (*HHI*) and even-numbered models use the concentration ratio (*CR3*) to account for market structure. Dependent variables are $Z\text{-}score_{ROA}$ (Tables 4 and 5), $Z\text{-}score_{ROE}$ (Tables 6 and 7). To examine the impact of efficiency on stability, Tables 4 and 6 use EFF_{SFA} whereas Tables 5 and 7 use $\mathrm{EFF}_{\mathrm{bootstrapDEA}}$.

4.2.1. The relationship between competition, efficiency and bank stability (Z-score$_{\mathbf{ROA}}$)

The figures in Table 4 indicate that the coefficients for Lerner indices are positive and significant for all models. This result provides strong evidence of a negative relationship between bank stability and bank competition; that is, a high degree of competition among banks may decrease their stability. The findings for East Asian countries support the traditional competition–fragility view. These results are in line with those reported by Turk Ariss (2010), Soedarmono et al. (2013) and Fu et al. (2014). An explanation for this may be that in a highly competitive market, banks grab market share by raising the deposit rates and cutting the lending rates to encourage customers to lend and take on debt. The narrow interest-rate spread can cause an increase in bank costs and a reduction in bank profits, thus impacting negatively on banks' stability. Besides that, banks can be more lenient in lending criteria, which reduces the quality of their loans. Therefore, banks are faced with bad loans or non-performing loans which increase bank risks and reduce bank stability. This also may be a reasonable cause of merger and acquisition (M&A) waves that have been happening strongly in East Asian banking systems. M&A activities may reduce competition in the banking system, increase bank size and market power, and help banks to benefit from economies of scale. In contrast, the results revealed that bank stability in the previous year and bank size seemed to contribute to an increase in bank stability. Larger banks became more stable than smaller ones, and stable banks were more stable in the next year. These results are significant for all models.

--- insert Table 4 about here ---

Bank risks also affected bank stability; however, the influences of credit risk and liquidity risk on bank stability were found to be in contrast. Surprisingly, the study showed that the coefficients for credit risk were positive whereas those for liquidity risk turned negative, and were significant for all models. These results suggest that there is a trade-off between credit risk and bank stability; nevertheless, banks could have increased their stability if they controlled liquidity risk. These findings are similar to the results of Soedarmono et al. (2013) in the case of emerging Asian markets. Turk Ariss (2010), Amidu (2013) and Hope et al. (2013) also found a positive link between loans to assets ratio and Z-score in developing and emerging markets. Their findings, like our results, are surprising as it is normally expected that a higher credit risk (measured by loans to total assets) or a lower liquidity risk (measured by deposits to total assets) leads to greater instability. When banks hold more loans in their assets, they may earn more income, but face liquidity risk and the borrowers' moral hazard. However, East Asian banks had a high deposits-to-assets ratio at approximately 86.5%, but a low rate of loans-to-total-assets at around 51.88% (see Table 2) on average over the 2004–2014 period. This may result in missed income-increasing opportunities for banks. Thus, banks can earn higher profit while they still avoid excessive risk-taking when granting more loans. In contrast, when banks hold a larger share of assets in deposits but have low volumes of lending, banks can increase deposit cost, reduce profits and capitalization ratio, which may result in a higher risk or less stability.

The macroeconomic condition of GDP growth was a factor affecting bank stability as well. The coefficients for GDP growth are negative and significant for almost all models except for Model 5. This result surprisingly suggests that banks become less stable in conditions of higher GDP growth. However, the finding is consistent with the study by Soedarmono et al. (2011), who examined the effects of market power and economic growth on stability of 12 Asian countries' commercial banks from 2001 to 2007. Amidu (2013) also suggested that banks in emerging and developing countries seem to be more unstable during periods of higher GDP growth; that is, banks may loosen their monitoring functions, and consequently increase the probability of insolvency during economic booms. In the case of East Asia, the negative relationship between GDP growth and stability found in this study can be explained by the observation that these countries had quite high growth rates. For example, the average GDP growth rates over 2004–2014 were 9.97% for China, 6.35% for Vietnam, 5.09% for Malaysia and 4.34% for Hong Kong. In particular, China's GDP growth rate reached 14.2% in 2007. In Vietnam, to maintain high GDP rates of growth in the 2004–2014 period, the central bank required the commercial banks to increase credit growth; this is normally achieved by decreasing the lending interest rates and credit standards, such as lower capital adequacy ratios, thereby increasing the insolvency risk. This requirement could have had a negative effect on bank stability.

The estimated coefficients for revenue diversification, listing status, and market shares are negative, whereas those for the inflation rate are positive. However, these findings are statistically insignificant for all models. Ownership and market concentration have positive impacts on bank stability for models using the conventional Lerner and the funding adjusted Lerner indices, but these relationships are negative for models using the efficiency-adjusted Lerner indices. These results are also not statistically significant.

Consistent with the results of Table 4, the coefficients for a one-period lag of $Z\text{-}score_{ROA}$, Lerner indices, bank size and credit risk are positive and significant in Table 5. Therefore, bank competition contributes to a decrease in bank stability ($Z\text{-}score_{ROA}$) whereas the other remaining factors improve bank stability. Moreover, liquidity risk and GDP growth have negative and significant influences on bank stability. These findings provide strong support to the results of Table 4.

As measured by DEA, the impact of bank efficiency on bank stability turns positive and significant for models using efficiency-adjusted Lerner indices. This result indicates that the significant impact of bank efficiency on bank stability depends on the specifications of Lerner indices and the approach to measuring bank efficiency. The positive effect of cost efficiency on stability confirms the "bad management" hypothesis and is in line with the study by Fiordelisi et al. (2011). According to this hypothesis, the managers of inefficient banks are bad at monitoring and controlling their operating expenses as well as managing the loan portfolio, which can lead to higher nonperforming loans and the probability of insolvency.

--- insert Table 5 about here ---

The coefficients on listing status of banks are negative and significant for Models 1 and 5 using the HHI variable. Hence, listed banks seem to have been less stable than unlisted banks. The crisis dummy is negatively related to bank stability, although this finding is only significant for Models 1, 2 and 3. This implies that banks are less stable during crisis periods.

4.2.2. The relationship between competition, efficiency and bank stability (*Z-score$_{ROE}$*)

As can be seen in Table 6, again, the signs of the coefficients for a one-period lag of the *Z-score$_{ROE}$* and all for specifications of Lerner indices are consistently positive and significant for all models. This implies that bank stability in the previous periods, as well as a decrease in the level of competition, enhances bank stability (as measured by the *Z-score$_{ROE}$*). Moreover, bank size is also positively related to bank stability. However, this finding is significant only when the efficiency-adjusted Lerner and funding-adjusted Lerner indices are used. Large banks may have been more stable than their smaller peers. Again, bank risks were found to be significant determinants of bank stability with contrasting impacts; credit risk had a positive influence on stability but liquidity risk had a negative effect on bank stability.

--- insert Table 6 about here ---

Market concentration has a positive effect on bank stability, but this finding is significant only for models using concentration ratios (*CR3*) with the conventional Lerner index and with the funding-adjusted Lerner index. This implies that banks in concentrated markets are more likely to be stable. Thus, in overall terms, lower competition and higher concentration could simultaneously improve bank stability. The estimated coefficients for revenue diversification were negative and significant only when conventional Lerner indices were used, suggesting that banks with higher non-interest income-to-revenue ratio may become less stable.

Bank efficiency (as measured by the SFA approach) had a negative – but statistically non-significant – impact on bank stability. Similarly, other bank characteristics such as the listing status, ownership and market share had a non-significant impact on bank stability. As far as the impact of macroeconomic conditions is concerned, only inflation was shown to be a significant and positive determinant of bank stability. It is worth mentioning that, except for Vietnam, all countries in the sample maintained a low inflation rate, with an annual average inflation rate under 3% during the sample period. An increase in the inflation rate normally leads to an increase in the interest rates on deposits and loans. Moreover, moderate inflation tends to enhance the stability of the economy and encourages business investment, thereby increasing the demand for borrowing. This can contribute to an increase in bank profits from loans, which is likely to have a positive effect on bank stability. The impact of both GDP growth and the GFC on bank stability is not statistically significant.

As shown in Table 7, the results of one-period lag of $Z\text{-}score_{ROE}$, all specifications of Lerner indices, bank size and liquidity risk are consistent with those in Tables 4 to 6. Here again, these findings strongly support the competition–fragility view. Moreover, a positive sign was consistently reported between cost efficiency (measured by DEA) and $Z\text{-}score_{ROE}$, which implies a positive effect of efficiency on stability in Table 7.

--- insert Table 7 about here ---

One-period lag of $Z\text{-}score_{ROE}$, size and market concentration (*CR3*) has a positive and significant effect on bank stability. Liquidity risk has a negative and significant impact on bank stability for models using the conventional Lerner and funding-adjusted Lerner indices. The impacts of revenue diversification and credit risk on bank stability are not significant. The coefficients for the inflation rate are positive and significant only when efficiency-adjusted Lerner indices are used, suggesting that higher inflation contributes to bank stability. Other remaining factors were not found to be significant determinants of bank stability.

5. Conclusion and policy implications

This paper investigates the impacts of both competition and cost efficiency on bank stability in four selected East Asian countries: China, Hong Kong, Malaysia, and Vietnam, over 2004–2014 using various alternative methods to measuring competition, efficiency and stability. The study uses both SFA and DEA approaches to measure cost efficiency. However, to avoid and correct for the bias in the cost efficiency scores measured by DEA, the study is the first to employ the sub-sampling bootstrap DEA method. The estimation results suggest that cost efficiency scores measured by SFA are higher than those by subsampling bootstrapped DEA. Spearman's rank order correlation coefficient between the SFA and DEA scores shows a moderate degree of consistency in the ranking of the selected East Asian banks. The average efficiency scores are highest for Vietnam, followed by China, Hong Kong and Malaysia. As far as competition among the selected East Asian banks is concerned, the estimated adjusted-Lerner indices are higher than the conventional ones. The estimates of bank competition are highest for the funding-adjusted Lerner indices, followed by the efficiency-adjusted Lerner and the conventional Lerner indices. It can be argued that the conventional Lerner indices may underestimate the market power of the East Asian banks. The funding- and efficiency-adjusted Lerner indices provide relatively more robust results. Regarding the measurement of bank stability, the rankings vary across the measurement techniques. The results of the estimated *Z*-scores suggest consistently that Vietnam had the least stable banking system, followed by China. The *Z*-scores$_{ROA}$ suggests that banks in Malaysia were the most stable whereas the *Z*-scores$_{ROE}$ indicates that those in Hong Kong were the most stable.

Additionally, our results support the traditional competition–fragility view, which suggests that competition may have a negative impact on bank stability. In other words, an increase in competition among East Asian banks may result in a decrease in their stability. However, the effect of cost efficiency on bank stability is not clear. Similarly, credit risk, bank size and market concentration may affect bank stability positively. Listed banks may be less stable than their non-listed peers. Liquidity risk and revenue diversification had negative effects on bank stability. Macroeconomic factors are also determinants of bank stability. Higher inflation may make banks become more stable; however, GDP growth may decrease the stability of banks. Finally, the results suggest that the GFC had a significant negative impact on bank stability.

These findings have important policy implications. First, the main results not only highlight the positive correlation between the Lerner indices and bank stability but also reveal the positive relationship between the concentration ratio and bank stability. The results strongly support the "competition–fragility" view, which states that banks with more market power are more stable. One strategy to stabilize the banking sector is to encourage and facilitate mergers of small and medium-sized banks. Mergers of smaller banks with strong banks can also improve the financial performance of the banking sector. Nevertheless, to prevent excessive concentration in the banking sector, regulators would need to be cautious in approving mergers. In addition, certain entry barriers such as minimum capital requirements may be needed to promote financial soundness.

While national governments can pursue the sort of policies recommended above, such as bank consolidation and greater capital requirements, the degree of international integration of markets requires international co-ordination of policy to provide insurance against crises, whether domestic or arising from international contagion. Since the GFC, the G20 has been working through the Financial Stability Board (FSB, 2018) to improve the Global Financial Safety Net (GFSN). These improvements focus on four main areas: sufficient foreign reserves and fiscal space at the national level; bilateral swap lines between Central Banks; Regional Financing Arrangements; the IMF as provider of a global backstop (Cheng, 2016). Although there is considerable debate around the adequacy of the GFSN (IMF, 2016), particularly in the case of emerging economies, there is a high level of commitment towards its continuous improvement.

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Table 1

Variable Definitions.

Variable	Proxy	Definition
Dependent variables		
Z-score$_{ROA}$	Z-score based on ROA criteria	The rate of the sum of ROA and equity ratio to the standard deviation of ROA
Z-score$_{ROE}$	Z-score based on ROE criteria	The rate of the sum of ROE and equity ratio to the standard deviation of ROE
Independent variables		
L_{CON}	Conventional Lerner index	A proportion of the difference between price and marginal cost to price
L_{EFF}	Efficiency-adjusted Lerner index	Lerner Index is derived from a single structure model which allows for the simultaneous estimation of both bank efficiency and the degree of market power
L_{FUND}	Funding-adjusted Lerner index	Lerner Index is adjusted for the market power by removing funding costs in the translog cost function to estimate marginal cost
EFF_{SFA}	SFA cost efficiency	Cost efficiency scores are estimated using the SFA approach
$EFF_{bootstrapDEA}$	DEA cost efficiency	Cost efficiency scores are estimated using the subsampling bootstrapped DEA approach
Control variables		
Bank-specific control variables		
SIZE	Bank size	The natural logarithm of total assets
RD	Revenue diversification	Non-interest income / total revenue
LIST	Listing status	A dummy variable takes a value of one if the bank is publicly listed and zero otherwise
OWNER	Ownership structure	OWNER = 1 for the state-owned commercial bank
		OWNER = 0 for the joint-stock commercial banks
CRISK	Credit risk	Ratio of loans to assets

LRISK	Liquidity risk	Ratio of deposits to assets
MS	Deposit market share	Total deposits of a bank / total deposits of all the banks
Industry-specific control variables		
HHI	Herfindahl Hirschman index	Sum of squares of the market share of each bank competing in the bank industry
CR3	Concentration ratio	Total assets of the three largest banks / total assets of all the banks
Macroeconomic control variables		
INF	Annual inflation rate	Annual inflation rate
GDP	Annual GDP growth rate	Annual GDP growth rate
CRISIS	Global financial crisis	Takes the value of one for 2009 and zero otherwise
Instrumental variables		
L.LERNER	Lagged Lerner index	The Lerner variable lagged by one year
CIR	Cost to income ratio	Cost to income ratio
LGROW	Loan growth	Growth of gross loans

Table 2

Summary Statistics of Bank-specific, Industry-specific and Macroeconomic variables.

Variable Name	Obs	Mean	Std. Dev.	Min	Max
Bank-specific characteristics					
Bank size (*SIZE*)	1040	15.9248	2.2858	9.4811	21.6510
Revenue diversification (*RD*)	1039	0.1436	0.1117	-0.2300	0.7787
Listing status (*LIST*)	1040	0.2548	0.4360	0	1
Ownership structure (*OWNER*)	1040	0.2000	0.4002	0	1
Credit risk (*CRISK*)	1040	0.5188	0.1578	0.0044	0.9239
Liquidity risk (*LRISK*)	1040	0.8650	0.0933	0.0661	1.0807
Deposit market share (*MS*)	1040	0.0422	0.0689	0.0000	0.4517
Industry-specific characteristics					
Herfindahl Hirschman index (*HHI*)	1040	0.1577	0.0631	0.0751	0.2771
Concentration ratio (*CR3*)	1040	0.5745	0.1006	0.3720	0.7206
Macroeconomic environment					
Annual inflation rate (*INF*)	1040	4.5594	4.4240	-0.7000	23.1150
Annual GDP growth rate (*GDP*)	1040	6.4378	3.1420	-2.4590	14.2
Global financial crisis (*CRISIS*)	1040	0.0909	0.2908	0	1

Notes: This table presents summary statistics of the sample of 99 commercial banks in the East Asia system over the period 2004–2014. *SIZE* is in logarithms. *INF* and *GDP* are in percentages. *LIST*, *OWNER* and *CRISIS* are in dummy form. Other variables are shown as ratios.
Source: Authors' calculations.

Table 3

Average estimation results for bank competition, cost efficiency, and stability over 2004–2014.

Country	Lerner index			Cost efficiency			Stability	
	L_{CON}	L_{EFF}	L_{FUND}	EFF_{SFA}	EFF_{DEA}	$EFF_{bootstrapDEA}$	$Z\text{-}score_{ROA}$	$Z\text{-}score_{ROE}$
China	0.3324	0.4351	0.6942	0.9424	0.8194	0.7794	25.5661	5.6600
Hong Kong	0.3063	0.5850	0.6990	0.8987	0.7482	0.7070	33.1442	7.1547
Malaysia	0.2832	0.5937	0.7661	0.7823	0.6698	0.5995	41.3236	7.1010
Vietnam	0.1515	0.4760	0.7781	0.9460	0.8352	0.8021	22.0533	4.3980

Notes: The conventional Lerner index (L_{CON}) is a proportion of the difference between price and marginal cost to price. The efficiency-adjusted Lerner index (L_{EFF})is the Lerner index derived from a single-structure model, which allows for the simultaneous estimation of both bank efficiency and the degree of market power. The funding-adjusted Lerner index (L_{FUND}) is the Lerner Index adjusted for market power by removing funding costs in the translog cost function to estimate marginal cost. A higher (lower) Lerner index is associated with a lower (higher) bank competition level. EFF_{SFA} ($EFF_{bootstrapDEA}$) is the cost efficiency score which is estimated using the SFA approach (the subsampling bootstrapped DEA approach). Cost efficiency is the ratio of a bank's estimated minimum cost to produce a certain output to the actual cost of production. Efficiency scores lie between 0 (least efficient) and 1 (most efficient). $Z\text{-}score_{ROA}$ ($Z\text{-}score_{ROE}$) is the rate of the sum of *ROA* (*ROE*) and equity ratio to the standard deviation of *ROA* (*ROE*). Higher Z-scores indicate more bank stability. All variables are expressed as ratios.

Source: Authors' calculations.

Table 4

The impact of competition and efficiency (*EFF_{SFA}*) on stability (*$Z\text{-}score_{ROA}$*).

Dependent variable: *$Z\text{-}score_{ROA}$*						
	(1)	(2)	(3)	(4)	(5)	(6)
L.*$Z\text{-}score_{ROA}$*	0.7903***	0.7926***	0.7759***	0.7783***	0.7794***	0.7819***
EFF_{SFA}	-5.1195	-5.5923	-1.0278	-0.9068	-1.3055	-1.2210
L_{CON}	8.9070***	8.5681***				
L_{EFF}			8.6639***	6.6972*		
L_{FUND}					8.0305**	7.8199**
SIZE	0.6138**	0.6029**	1.2744***	1.1529***	1.1259***	1.0532***
RD	-5.2660	-5.9825	-3.9411	-3.6827	-0.0243	-0.4632
LIST	-1.4514	-1.2558	-1.0958	-1.3231	-1.4819	-1.2555
OWNER	0.7131	0.7592	-0.7087	-0.1727	0.1156	0.0570
CRISK	7.1074***	7.4527***	7.7214***	7.5227***	7.9646***	7.5920***
LRISK	-20.4938***	-20.3091***	-17.1131***	-17.8543**	-18.4765***	-18.1439***
MS	-3.3261	-8.4189	-10.2221	-12.0262	-9.8050	-6.2884
HHI	2.2322		-3.8242		3.0095	
CR3		4.1352		2.0230		4.4299
INF	0.0574	0.0815	0.0728	0.0836	0.0195	0.0366
GDP	-0.2076*	-0.2208*	-0.2026**	-0.1870**	-0.1682	-0.1854*
CRISIS	-1.0501	-0.9849	-0.8458	-0.7910	-0.5554	-0.6445
_cons	14.7208**	13.2333**	-3.3066	-1.7139	-2.8756	-3.9253
p-value AR(1)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
p-value AR(2)	0.234	0.233	0.279	0.283	0.272	0.270
p-value Hansen test	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99

Notes: Results from the six variants of the dynamic panel-data model to explain the implications of competition and efficiency on bank stability. Columns 1-2 use the conventional Lerner index (*L_{CON}*), Columns 3-4 use the efficiency-adjusted Lerner index (*L_{EFF}*) while Columns 5-6 use the funding-adjusted Lerner index (*L_{FUND}*). Odd-numbered columns use the Herfindahl Hirschman index (HHI) and even-numbered columns use the concentration ratio (*CR3*) to account for market structure. *$Z\text{-}score_{ROA}$* is the rate of the sum of ROA and equity ratio to the standard deviation of ROA. Cost efficiency scores (*EFF_{SFA}*) are estimated using the SFA approach. *SIZE* is the natural logarithm of total assets. *RD* is the ratio of non-interest income over total revenue. *CRISK* is the ratio of loans to assets. *LRISK* is the ratio of deposits to assets. *LIST* is a dummy variable that takes a value of one for a listed bank and zero otherwise. *OWNER* is a dummy variable that takes a value of one for the state-owned commercial banks and zero otherwise. *MS* is the ratio of total deposits of a bank to total deposits of all the banks. *INF* is the annual inflation rate. *GDP* is the annual GDP growth rate. *CRISIS* is a dummy variable that takes a value of one for 2009 and zero otherwise. AR(1)/AR(2) is the Arellano-Bond tests for first and second order serial correlation, respectively.

* Coefficients that are significant at the 10% level; ** Coefficients that are significant at the 5% level; *** Coefficients that are significant at the 1% level.

Source: Authors' calculations.

Table 5

Effect of Competition and Efficiency ($EFF_{bootstrapDEA}$) on Stability ($Z\text{-}score_{ROA}$).

Dependent variable: $Z\text{-}score_{ROA}$						
	(1)	(2)	(3)	(4)	(5)	(6)
L. $Z\text{-}score_{ROA}$	0.7854***	0.7883***	0.7713***	0.7838***	0.7670***	0.7731***
$EFF_{bootstrapDEA}$	1.4767	2.0045	4.6920***	4.4229***	2.3695	2.8100
L_{CON}	7.2896***	6.3348**				
L_{EFF}			11.2887***	8.8430***		
L_{FUND}					9.1728**	7.9252**
SIZE	0.4223	0.4664*	1.2146***	1.0117***	1.0458***	0.9420***
RD	-2.3592	-2.6191	-0.8598	-1.6860	2.7519	1.5359
LIST	-1.7799*	-1.6336	-1.3163	-1.3368	-2.0261*	-1.4794
OWNER	1.6022	1.2909	-0.3290	0.6637	0.9468	0.4455
CRISK	5.8662**	6.0549**	5.7097**	5.6557**	7.2679***	6.0580**
LRISK	-19.6042***	-18.0657***	-13.1951**	-13.5752**	-16.9625**	-16.0425**
MS	-2.1751	-12.5550	-10.6004	-12.4327	-5.0142	-7.4076
HHI	0.7836		-8.2582		0.1882	
CR3		5.2226		0.5936		5.6964
INF	0.0013	0.0326	0.0236	0.0428	-0.0177	0.0142
GDP	-0.2535**	-0.2654**	-0.2597***	-0.2340**	-0.2020*	-0.2118**
CRISIS	-1.3497*	-1.2558*	-1.1595*	-1.0930	-0.9278	-0.7739
_cons	12.8618*	8.0596	-9.3231	-6.5878	-5.5544	-6.8553
p-value AR(1)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
p-value AR(2)	0.245	0.247	0.304	0.304	0.292	0.287
p-value Hansen test	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99

Notes: Results from the six variants of the dynamic panel-data model to explain the implications of competition and efficiency on bank stability. Columns 1-2 use the conventional Lerner index (L_{CON}), Columns 3-4 use the efficiency-adjusted Lerner index (L_{EFF}) while Columns 5-6 use the funding-adjusted Lerner index (L_{FUND}). Odd-numbered columns use the Herfindahl Hirschman index (HHI) and even-numbered columns use the concentration ratio (*CR3*) to account for market structure. $Z\text{-}score_{ROA}$ is the rate of the sum of ROA and equity ratio to the standard deviation of ROA. Cost efficiency scores ($EFF_{bootstrapDEA}$) are estimated using the subsampling bootstrapped DEA approach. *SIZE* is the natural logarithm of total assets. *RD* is the ratio of non-interest income over total revenue. *CRISK* is the ratio of loans to assets. *LRISK* is the ratio of deposits to assets. *LIST* is a dummy variable that takes a value of one for a listed bank and zero otherwise. *OWNER* is a dummy variable that takes a value of one for the state-owned commercial banks and zero otherwise. *MS* is the ratio of total deposits of a bank to total deposits of all the banks. *INF* is the annual inflation rate. *GDP* is the annual GDP growth rate. *CRISIS* is a dummy variable that takes a value of one for 2009 and zero otherwise. AR(1)/AR(2) is the Arellano-Bond tests for first and second order serial correlation, respectively.

* Coefficients that are significant at the 10% level; ** Coefficients that are significant at the 5% level; *** Coefficients that are significant at the 1% level.

Source: Authors' calculations.

Table 6

Effect of Competition and Efficiency (EFF_{SFA}) on Stability ($Z\text{-}score_{ROE}$).

Dependent variable: $Z\text{-}score_{ROE}$						
	(1)	(2)	(3)	(4)	(5)	(6)
L. $Z\text{-}score_{ROE}$	0.7656***	0.7724***	0.8019***	0.7990***	0.7938***	0.7935***
EFF_{SFA}	-1.1179	-0.9149	-0.0910	-0.0091	-0.0353	-0.0122
L_{CON}	2.5910***	2.4277***				
L_{EFF}			1.7670***	1.5523**		
L_{FUND}					3.1165***	2.9935***
SIZE	0.0597	0.0602	0.1882***	0.1723**	0.2192***	0.2065***
RD	-1.4530**	-1.4765**	-0.5398	-0.6718	0.3196	0.1759
LIST	0.0380	-0.0014	-0.0436	-0.0407	0.0327	0.0402
OWNER	0.2312	0.2402	0.1175	0.0148	-0.1394	-0.1649
CRISK	1.0424**	0.9257*	0.8939*	0.8709*	1.0896*	1.0515*
LRISK	-5.7483***	-5.4905***	-3.6731*	-3.9761**	-3.9063*	-3.9284**
MS	0.5064	-0.5517	-0.6993	-0.2055	0.7427	0.6390
HHI	1.3619		0.1142		1.3493	
CR3		1.3192**		0.6674		1.1857*
INF	0.0186	0.0216*	0.0278**	0.0272**	0.0143	0.0167
GDP	-0.0080	-0.0169	0.0016	0.0027	-0.0028	-0.0083
CRISIS	-0.0159	-0.0336	0.0790	0.0867	0.1063	0.0931
_cons	5.0746**	4.2718**	-0.0659	0.1897	-2.0616	-2.1650
p-value AR(1)	0.007	0.007	0.005	0.005	0.005	0.005
p-value AR(2)	0.244	0.230	0.270	0.275	0.221	0.218
p-value Hansen test	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99

Notes: Results from the six variants of the dynamic panel-data model to explain the implications of competition and efficiency on bank stability. Columns 1-2 use the conventional Lerner index (L_{CON}), Columns 3-4 use the efficiency-adjusted Lerner index (L_{EFF}) while Columns 5-6 use the funding-adjusted Lerner index (L_{FUND}). Odd-numbered columns use the Herfindahl Hirschman index (HHI) and even-numbered columns use the concentration ratio (*CR3*) to account for market structure. $Z\text{-}score_{ROE}$ is the rate of the sum of ROE and equity ratio to the standard deviation of ROE. Cost efficiency scores (EFF_{SFA}) are estimated using the SFA approach. *SIZE* is the natural logarithm of total assets. *RD* is the ratio of non-interest income over total revenue. *CRISK* is the ratio of loans to assets. *LRISK* is the ratio of deposits to assets. *LIST* is a dummy variable that takes a value of one for a listed bank and zero otherwise. *OWNER* is a dummy variable that takes a value of one for the state-owned commercial banks and zero otherwise. *MS* is the ratio of total deposits of a bank to total deposits of all the banks. *INF* is the annual inflation rate. *GDP* is the annual GDP growth rate. *CRISIS* is a dummy variable that takes a value of one for 2009 and zero otherwise. AR(1)/AR(2) is the Arellano-Bond tests for first and second order serial correlation, respectively.

* Coefficients that are significant at the 10% level; ** Coefficients that are significant at the 5% level; *** Coefficients that are significant at the 1% level.

Source: Authors' calculations.

Table 7

Effect of Competition and Efficiency ($EFF_{bootstrapDEA}$) on Stability ($Z\text{-}score_{ROE}$).

Dependent variable: $Z\text{-}score_{ROE}$						
	(1)	(2)	(3)	(4)	(5)	(6)
L. $Z\text{-}score_{ROE}$	0.7839***	0.7779***	0.7913***	0.7914***	0.7820***	0.7890***
$EFF_{bootstrapDEA}$	0.2803	0.2867	1.2021***	1.1847***	0.7652*	0.7699*
L_{CON}	2.2547***	2.2316***				
L_{EFF}			2.5217***	2.2573***		
L_{FUND}					3.2304***	3.1040***
SIZE	0.0334	0.0320	0.1856***	0.1799**	0.2127***	0.1891**
RD	-0.9070	-0.9240	-0.3059	-0.2944	0.7895	0.6982
LIST	-0.0791	-0.0091	-0.0836	-0.0794	-0.0224	-0.0302
OWNER	0.2171	0.2605	0.0812	0.0161	-0.0522	-0.0962
CRISK	0.6535	0.6309	0.6048	0.6602	0.8822	0.8396
LRISK	-5.2686***	-5.2735***	-3.1186*	-3.2206	-3.6706*	-3.6081*
MS	0.1939	-0.0649	-0.9603	-0.5851	-0.5604	-0.3693
HHI	1.0895		-0.5513		1.2966	
CR3		1.2740**		0.2342		1.1334*
INF	0.0090	0.0139	0.0192*	0.0206*	0.0066	0.0094
GDP	-0.0112	-0.0150	-0.0128	-0.0064	-0.0074	-0.0131
CRISIS	-0.0483	-0.0456	-0.0138	0.0371	0.0654	0.0394
_cons	4.1175**	3.6395**	-1.3814	-1.3413	-2.5854	-2.6081
p-value AR(1)	0.007	0.007	0.005	0.005	0.005	0.005
p-value AR(2)	0.260	0.248	0.297	0.300	0.239	0.232
p-value Hansen test	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99

Notes: Results from the six variants of the dynamic panel-data model to explain the implications of competition and efficiency on bank stability. Columns 1-2 use the conventional Lerner index (L_{CON}), Columns 3-4 use the efficiency-adjusted Lerner index (L_{EFF}) while Columns 5-6 use the funding-adjusted Lerner index (L_{FUND}). Odd-numbered columns use the Herfindahl Hirschman index (HHI) and even-numbered columns use the concentration ratio (*CR3*) to account for market structure. $Z\text{-}score_{ROE}$ is the rate of the sum of ROE and equity ratio to the standard deviation of ROE. Cost efficiency scores ($EFF_{bootstrapDEA}$) are estimated using the subsampling bootstrapped DEA approach. *SIZE* is the natural logarithm of total assets. *RD* is the ratio of non-interest income over total revenue. *CRISK* is the ratio of loans to assets. *LRISK* is the ratio of deposits to assets. *LIST* is a dummy variable that takes a value of one for a listed bank and zero otherwise. *OWNER* is a dummy variable that takes a value of one for the state-owned commercial banks and zero otherwise. *MS* is the ratio of total deposits of a bank to total deposits of all the banks. *INF* is the annual inflation rate. *GDP* is the annual GDP growth rate. *CRISIS* is a dummy variable that takes a value of one for 2009 and zero otherwise. AR(1)/AR(2) is the Arellano-Bond tests for first and second order serial correlation, respectively.

* Coefficients that are significant at the 10% level; ** Coefficients that are significant at the 5% level; *** Coefficients that are significant at the 1% level.

Source: Author's calculations.

Appendix A. Measuring cost efficiency by SFA.

Banks can be thought of as multi-product firms (Sealey & Lindley, 1977) which produce a number of different outputs (y_i) by using a number of different inputs (x_i) at given prices (w_i) with the objective of minimizing total costs. Total cost is expressed as a function of two outputs (total loans (y_1) and other earning assets (y_2)), three input prices (the price of deposits (w_1), the price of physical capital (w_2), and the price of labor (w_3)), and technical change (*Trend*). Time trend variables, used as control variables to account for heterogeneity across banks, take into account technical change that includes changes in the cost function over time. Total costs and input prices are scaled by the price of labor (w_3) to correct for heteroskedasticity.

Using SFA, cost efficiency scores are estimated from the translog functional form:

$$\begin{aligned}\ln\frac{TC_{kt}}{w_{3,kt}} &= \alpha_0 + \sum_{i=1}^{2}\alpha_i \ln y_{i,kt} + \sum_{i=1}^{2}\beta_i \ln\left(\frac{w_{i,kt}}{w_{3,kt}}\right) + \delta_1\, Trend + \frac{1}{2}\sum_{i=1}^{2}\sum_{j=1}^{2}\varepsilon_{ij}\ln y_{i,kt}\ln y_{j,kt} \\ &+ \frac{1}{2}\sum_{i=1}^{2}\sum_{j=1}^{2}\theta_{ij}\ln\left(\frac{w_{i,kt}}{w_{3,kt}}\right)\ln\left(\frac{w_{j,kt}}{w_{3,kt}}\right) + \frac{1}{2}\delta_2\, Trend + \sum_{i=1}^{2}\sum_{j=1}^{2}\vartheta_{ij}\ln y_{i,kt}\ln\left(\frac{w_{j,kt}}{w_{3,kt}}\right) \\ &+ \sum_{i=1}^{2}\rho_i \ln y_{i,kt}\, Trend + \sum_{i=1}^{2}\varphi_i \ln\left(\frac{w_{i,kt}}{w_{3,kt}}\right) Trend + u_{kt} + v_{kt}\end{aligned} \tag{A.1}$$

The technical inefficiency effect (u_{kt}) of bank k ($k = 1, 2, \ldots, K$) at year t ($t = 1, 2, \ldots T$) is specified as follows:

$$u_{kt} = \delta_0 + \sum_{i=1}^{4}\delta_i E_{i,kt} + W_{kt} \tag{A.2}$$

where W is a random variable.

Explanatory variables (E_i), used to control for the differences in the inefficiency effects, include the market share (*MS*), the Herfindahl-Hirschman index (*HHI*), the listing status (*LIST*) and the ownership (*OWNER*). The assumption is that $W_{kt} \geq -E_{kt}\,\delta$ must hold to be consistent with the assumption that u_{kt} is a non-negative truncation of N ($E_{kt}\delta$, σ_u^2).

The translog cost function becomes linear homogeneous in input price when the following conditions hold:

$$\sum_{i=1}^{3}\beta_i = 1 \; ; \quad \sum_{i=1}^{3}\theta_{ij} = 0 \; ; \quad \sum_{i=1}^{3}\vartheta_i = 0 \; ; \quad \sum_{i=1}^{3}\varphi_i = 0$$

Due to symmetry of the Hessian: $\varepsilon_{ij} = \varepsilon_{ji}$; $\theta_{ij} = \theta_{ji}$

The error terms (ε) are separated into the random error (v) and the inefficiency (u) in the functional form of the frontier, thus they capture impacts of the statistical noise and the inefficiency. The components of error terms are distributed independently; v is assumed to be independent and identically distributed with mean zero and variance σ_v^2 as a normal distribution, $N(0, \sigma_v^2)$; u follows a non-negative truncated distribution with mean $\mu = E\delta$ and variance σ_u^2; that is, $u \sim$ iid $N^+(E\delta, \sigma_u^2)$. The term ε equals $v + u$ where v is a symmetric error that includes both the possibility of luck and measurement errors to account for the statistic noise; u is a non-negative random disturbance term that represents the cost inefficiency score. Equation (A.1) is estimated separately for each country.

Cost efficiency is defined as the ratio of a bank's estimated minimum cost to produce a certain output to the actual cost of production (Berger & Mester, 1997; Coelli et al., 2005). Therefore, the cost-efficiency score (CE) of bank k in year t is calculated as:

$$CE_{kt} = \frac{\exp[\hat{f}(w_{kt}, y_{kt}, v_{kt})]}{\exp[\hat{f}(w_{kt}, y_{kt}, v_{kt})] \times \exp(\hat{u}_{kt})} = \exp(-\hat{u}_{kt}) \qquad \text{(A.3)}$$

Definitions of all variables are listed in Table A.1.

Table A.1

Cost Efficiency Measurement: Variable Definitions.

Symbol	Variable names	Description
TC	Total cost	Total cost
Outputs:		
y_1	Total loans	Total loans
y_2	Other earning assets	The sum of total securities and other investments
Inputs:		
x_1	Total deposits	Total funding
x_2	Total physical capital	Fixed assets
x_3	Labor	Personnel expenses
w_1	Price of deposits	The ratio of interest expenses to total funding
w_2	Price of physical capital	The ratio of other operating cost to fixed assets
w_3	Price of labor	The ratio of personnel expenses to total assets
Control variables:		
Trend	Technical change	Take values from 1 to 11 corresponding to the years from 2004 to 2014
Explanatory variables:		
MS	Market share	Total assets of a bank / total assets of all banks
HHI	Herfindahl-Hirschman index	Sum of the squares of the market share of each bank competing in the bank industry
LIST	Listing status	*LIST* =1 for the publicly listed bank
		LIST = 0 for the unlisted bank
OWNER	Ownership structure	*OWNER* = 1 for the state-owned commercial bank
		OWNER = 0 for the joint-stock commercial bank

Notes: *TC*, y_1, y_2, x_1, x_2, x_3 are in thousands of US dollars; w_1, w_2, w_3, *MS* and *HHI* are ratios.
The price of labor (i.e., the wage rate) is usually measured by the ratio of the personnel expenses to the number of employees. As the dataset does not provide sufficient details, following Maudos and De Guevara (2007), the ratio of personnel expenses to total assets is used as a proxy for the price of labor.

Appendix B. Translog cost functions for estimating marginal cost

The conventional Lerner index

Following De Guevara et al. (2005), Fungáčová et al. (2013), Beck et al. (2013) and others, total cost (*TC*) is expressed as a function of one single output (*y*: total assets), three input prices (w_i) and technical change (*Trend*) [4] as follows:

$$\ln TC_{kt} = \alpha_0 + \alpha_1 \ln y_{kt} + \sum_{i=1}^{3} \beta_i \ln w_{i,kt} + \delta_1 Trend + \frac{1}{2}\alpha_2 \ln y_{kt}^2 + \frac{1}{2}\sum_{i=1}^{3}\sum_{j=1}^{3} \theta_{ij} \ln w_{i,kt} \ln w_{j,kt}$$
$$+ \frac{1}{2}\delta_2 Trend^2 + \sum_{i=1}^{3} \vartheta_i \ln y_{kt} \ln w_{i,kt} + \rho_i \ln y_{kt} Trend + \sum_{i=1}^{3} \varphi_i \ln w_{i,kt} Trend + \varepsilon_{kt} \quad \text{(B.1)}$$

Using the Ordinary least squares (OLS) regression, marginal cost (*MC*) is derived from the translog cost function:

$$MC_{kt} = \frac{TC_{kt}}{y_{kt}}\left[\alpha_1 + \alpha_2 \ln y_{kt} + \sum_{i=1}^{3} \vartheta_i \ln w_{i,kt} + \rho_1 Trend\right] \quad \text{(B.2)}$$

The funding-adjusted Lerner index

The translog cost function to estimate the marginal cost ($\widehat{MC}_{FUND}$) and total cost ($\widehat{TC}$) is adjusted as follows:

$$\ln TC_{kt} = \alpha_0 + \alpha_1 \ln y_{kt} + \sum_{i=1}^{2} \beta_i \ln w_{i,kt} + \delta_1 Trend + \frac{1}{2}\alpha_2 \ln y_{kt}^2 + \frac{1}{2}\sum_{i=1}^{2}\sum_{j=1}^{2} \theta_{ij} \ln w_{i,kt} \ln w_{j,kt}$$
$$+ \frac{1}{2}\delta_2 Trend^2 + \sum_{i=1}^{2} \vartheta_i \ln y_{kt} \ln w_{i,kt} + \rho_i \ln y_{kt} Trend + \sum_{i=1}^{2} \varphi_i \ln w_{i,kt} Trend + u_{kt} + v_{kt} \quad \text{(B.3)}$$

where *TC*, w_1 and w_2 are the total operating costs, the price of physical capital and the price of labor, respectively.

[4] The input prices (w_i) and technical change (*Trend*) are defined in Table A.1.