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Full Length Research Paper

Efficiency, productivity change and corporate value during the period of financial crisis: Evidence from Asia banks

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This study explored efficiency in the banking industry and applies non -parametric frontier analysis (DEA) to measure the relative efficiency of the banking industry in nine Eastern-Asia countries from 1993 to 2002. Malmquist decomposition was carried out to distinguish efficiency changes from technical changes. The empirical results showed that after the Asian financial crisis (1998 to 2002), technical efficiency was decreasing in Indonesia, Thailand and Malaysia. Furthermore, after the Asian financial crisis the "scale efficiency change ($\Delta SE_i^{t,t+1}$)" and "residual index of scale change under VRS ($\Delta S_i^{t,t+1}$) were important factors affecting the corporate value of banks in Eastern-Asia countries. These findings offer implications for investors in decision-making and considerable policy relevance. From the regulatory and supervisory perspective, the policy direction will be directed towards enhancing the resilience and efficiency of the financial institutions with the aim of intensifying the stability of the financial system.

Key words: Technical efficiency, productivity, Malmquist index, Data Envelopment Analysis (DEA), corporate value.

INTRODUCTION

In the past two decades as the global economy has grown and prospered, the banking industry has been faced with major reforms and challenges for primarily two reasons: the advancement of information technology, and deregulation (and re-regulation), which has prompted banks around the world to seek innovation and breakthroughs in their business practices. "Regulation" constrains the bank's expansion of service areas and product lines. However, banks are sometimes able to bypass regulatory processes through financial innovation, and through the adjustment process, become more competitive and productive. Therefore, how regulation and technological transformation affects the practices and productivity of banks has become the focus of a number of empirical studies. Berger et al. (1995) examined the technological and regulatory changes in the US banking industry, Altunbas et al. (2000); Molyneux et al. (1996) studied Japanese banks, and Altunbas and Molyneux (1996) investigated the banking industry in Europe. Sufian and Habibullah (2009) examined the impact of mergers and acquisitions on the technical efficiency of the Malaysian banking sector.

Parametric and non-parametric approaches have been employed to measure banking productivity. Gascón et al. (2002) studied the trends of banking productivity in Europe, North America and Japan from 1989 to 1998 and found different productivity patterns among different geographic areas, which led to varying economic efficiency and productivity changes. The majority of the past literature has examined the trends of productivity change in the 1980s and early 1990s. To date, there are no empirical studies comparing banking productivity among Asian countries. In addition, past empirical studies have not made direct comparisons of productivity changes across geographic areas over the same period, not only due to the traditional distinction between parametric and non-parametric approaches but also due to differences in the choice of productivity decomposition.

The existence of alternative time intervals and the size of the banks included in the sample have precluded a systemic and in-depth analysis and cross-country comparison of productivity variations in the banking industry in Asia. This article extends the past empirical study period to the 2000s and compares countries in Asia, in particular changes in the banking productivity of Asian countries before and after the 1997 Asian financial crisis. In addition, to examine the extent of banking productivity change and the effect of such change on other banks, this study employs non-parametric Data Envelopment Analysis (DEA) to evaluate and decompose the Malmquist productivity indexes, and attempts to explore the causes for banking productivity change.

The objectives of this study are as follows: (1) measure the level of productivity change and trends of banks in nine Eastern-Asia countries (Japan, Taiwan, Indonesia, Hong Kong, Thailand, Malaysia, Philippines, Singapore, and Korea) during 1993~2002 using Malmquist productivity indexes as computed by linear programming; (2) decompose efficiency changes and technical changes into four components (pure efficiency change, scale efficiency change, technical change under variable returns to scale (VRS) and residual index of scale change under variable returns to scale (VRS)), to further explore the reasons for banking productivity changes; (3) compare the trends of banking productivity change in nine Eastern-Asia countries and analyze the cross-country differences; and finally (4) investigate the correlation between productivity change and corporate value in the banking industry of Eastern-Asia countries to see whether there is a significant difference in such correlation before and after the Asian financial crisis.

The remainder of the paper is organized as follows: A reviews on the theoretical and empirical literature about bank efficiency is presented. The econometric framework, empirical specification and data used in this study are discussed; detailed discussion of the empirical results is then presented and finally conclusions.

LITERATURE REVIEW

Studies on efficiency

Topics concerning productivity change and its sources in financial intermediaries have drawn increasing interest from scholars in recent years, resulting in a wide range of research issues. This line of research has mostly investigated the efficiency and productivity of banks from the perspective of how productivity changes are influenced by changes in regulation, differences across countries, and the effects of innovation and technological processes. Elyasiani and Mehdian (1990) respectively used U.S. data from 1979 and 1986 as proxies for the pre and post-deregulation periods, and used DEA to measure the efficiency scores for samples of US banks from those two years. Their study found that the technical efficiency of large banks declined by 3% over an eight-year period, and from a time dependent ratio analysis, the technical efficiency of the US banking industry dropped 2%, indicating the absence of any significant difference in the technical efficiency of US banks following banking deregulation.

Subsequent studies have focused on productivity changes in U.S. commercial banks following deregulation in the 1980s, with particular emphasis on either total factor productivity changes or technological progress. Mukherjee et al. (2001) explored productivity changes of large commercial banks during the period from 1984 to 1990, finding an overall productivity change rate of 4.5% per year on average. This study also showed that larger banks and a higher specialization of products in general have higher productivity. However, Humphrey (1991,1993), Hunter and Timme (1991) and Bauer et al. (1993), using parametric methods to measure productivity change, and Wheelock and Wilson (1999), using a non-parametric approach, found either little, zero or negative growth in total productivity in the majority of commercial banks. On the other hand, Alam (2001) studied the productivity of US commercial banks over the period 1980 to 1989, finding that changes in productivity are mainly attributable to “technological change” rather than scale changes or convergence to the productivity frontier. Whelock and Wilson (1999) investigated the productivity change of U.S. banks during the period from 1984 to 1993. They found that the banking industry overall experienced declines in technical efficiency productivity. They attributed this decline in productivity to a minority of banks advancing the productivity frontier forward, while the rest remained behind during the time interval. However, their empirical results did find technological progress over the same period.

In their studies of European banks, Grifell-Tatjé and Lovell (1997) found that commercial banks in Spain had lower productivity changes than savings banks from 1986 to 1993. In a subsequent paper, Grifell-Tatjé and Lovell (1999) analyzed the sources of profit growth in Spanish commercial banks from 1987 to 1994. They found a large increase in bank productivity, which was offset by a large negative price effect due to increasing competition and an increase in productivity that could be entirely attributed to technological progress. Kumbhakar et al. (2001) and Maudos (1996) drew the same conclusion. However, the empirical study of Portuguese banks by Mendes and Rebelo (1999) reported the opposite. With respect to the productivity change of banks in Asia, Fukuyama (1995), in a study of 155 Japanese banks over from 1989 to 1991, reported relatively high indexes of technological progress. Leightner and Lovell (1998) also reported increases in total productivity in a sample of Thai banks during 1989 to 94. Jan and Liu (2006) explored changes in technical efficiency and productivity of banks in Taiwan from 1987 to 2000 following the implementation of financial liberalization in the aftermath of Asian financial crisis. They found that the average productivity of the overall banking industry was exhibiting a growth trend by 1992, after new banks were allowed to be established, while the technical efficiency of the old banks decreased and became lower than that of the new banks.

The above studies found that banks around the world experienced productivity change and technological progress over during the late 1980s and early 1900s. However, those studies generally adopted "variations in productivity over time" as the main analytical approach. It shows that further empirical analysis is required to reach a consistent conclusion on variation in the banking efficiency. Some studies have carried out analyses across countries. Berg et al. (1993) conducted cross-country comparisons using cross-section data on banks from three Nordic countries and finds significant differences between them. Chaffai et al. (2001) used a Malmquist decomposition to explain productivity gaps in banking industries across four major European countries, separating productivity differences into purely technological differences and differences due to environmental or external factors.

In summary, past studies have primarily addressed the trends of bank productivity changes in the 1980s and early 1900s, while the comparison of cross-country productivity after 1990 has been scarce, in particular cross-country comparisons of Asian banks. On the other hand, empirical studies of banks in Taiwan lack long-term trend analyses. These studies preclude a direct comparison of productivity changes in different geographical areas over the same time interval, due to differences in the methodology chosen to measure efficiency and productivity. This is not only due to the traditional difference between parametric and non- parametric approaches, but also due to differences in the productivity decomposition methods chosen.

Relationship between productivity changes and corporate value

The examination of the correlation between banking productivity changes and corporate value can verify whether the performance of bank's stock returns can be explained by productivity change. The cross-country comparison helps shed light on whether differences in banking productivity change in different regions will produce different influence on the performance of bank stocks. Past studies have typically used capital adequacy, risk-based assets, non-performing loan ratios and the CAMELs system for bank ratings, while few have assessed bank performance based on the extent of productivity change or stock value performance. Brealey et al. (1991) asserted that in a semi-strong efficient market where most of the information available is incorporated into stock prices, "stock value" is the best unbiased estimate of "value creation for shareholders."

As productivity change has a conspicuous effect on value creation, it is reasonable to surmise that firms with higher productivity change will perform better in the stock market.

According to the empirical study of Gascón et al. (2002), Tobin's Q (Tobin, 1969) may be a stable measure of business performance, but it refers entirely to past performance without considering expected future performance, and therefore, empirically is more difficult to account for asset replacement costs. Gascón et al. (2002) also showed that the ranking of banks will be the same either according to stock performance or according to Tobin's Q. Gascón et al. (2002) sampled banks in European countries from 1989 to 1998 and used "stock value" performance as an estimate of "value creation for shareholders" to explore the correlation between efficiency change and market returns. The results showed a strong positive relationship between pure efficiency change and market returns, and a strong positive relationship between technical change and bank market returns. However, there is no significant correlation between scale efficiency change and market value. It implies that improvement in the pure efficiency of European banks is accompanied by an increase in market value. In a study of the relationship between productivity change and corporate value of 706 listed firms in the manufacturing sector of the U.K. from 1996 to 2000, Amess and Girma (2004) found that changes in technical efficiency and labour productivity are indeed influenced by changes in corporate value, however changes in technical efficiency and labour productivity do not have any effect on changes in corporate value. The studies cited above target mainly European countries, while cross-country comparisons in Asia have been few, in particular cross-country comparisons of bank pro-ductivity before and after the 1997 Asian financial crisis. Thus, cross -country empirical studies targeting Asia are called for to address this void.

METHODOLOGY

This study assessed efficiency and productivity changes of banks using mainly non-parametric approaches to compute and decompose the Malmquist indexes. Several different decompositions of the Malmquist indexes have been proposed. The most commonly used are from Färe et al. (1994), which assumes a constant return to scale (CRS), and from Ray and Desli (1997), which proposes a variable return to scale (VRS). Previous literature on the analysis of bank productivity has employed both of these approaches. Alam (2001) used the Malmquist productivity decomposition suggested by Färe et al. (1994); Mukherjee et al. (2001) followed the proposition of Ray and Desli (1997). A third decomposition suggested by Simar and Wilson (1998) and Zofio and Lovell (1998) extends the proposition of Ray and Desli (1997) to extract more productivity change components. Under this method, the efficiency change and technical change components are further decomposed into four components. Wheelock and Wilson (1999) have applied this approach to the study of productivity changes in banking. This study adopted the decomposition methods of Simar and Wilson (1998) and Zofio and Lovell (1998) to extract more productivity change components (Gascón et al., 2002). The decompositions of Malmquist Productivity Index and non-parametric estimators are estimators are presented in Appendix 1.

Hypotheses, model and statistical methods

According to Brealey, Myers and Marcus (1991), in a semi-strong efficient market where most of the information available is incorporated into stock prices, “stock value” performance can be the best unbiased estimate of “value creation for shareholders.” The empirical study of Gascón et al. (2002) found that productivity change has a significant effect on the creation of corporate value. Thus, it is reasonable to deduce that banks with higher productivity changes should have better performance in the stock market. This study therefore proposed the following hypotheses. The modeling and statistical methods used are also discussed:

H_1^1 : Banks with higher productivity change indexes (pure efficiency change, scale efficiency change, technical change under variable returns to scale (VRS), and residual index of scale change under VRS have a higher corporate value.

$$\log\left(\frac{V_{i,t}}{V_{i,t-1}}\right) = \mu_{i,t} + Time + \delta_{i,t} * (\Delta PE_i^{t,t+1}) + \gamma_{i,t} * (\Delta SE_i^{t,t+1}) + \theta_{i,t} * (\Delta T_{BCC,i}^{t,t+1}) + \eta_{i,t} * (\Delta S_i^{t,t+1}) + \varphi_{i,t} \quad (1)$$

$H_1^1 : \delta_{i,t} \quad 0, \gamma_{i,t} \quad 0, \theta_{i,t} \quad 0, \eta_{i,t} \quad 0$

$V_{i,t}$: The market capitalization of bank i at period t, i.e. the closing price of bank i’s common stocks at the end of the year (Ps)$*$ weighted outstanding shares at the end of the year (CS). (t: 1993~2002)

$\Delta PE_i^{t,t+1}$: The “pure efficiency change” relative to the VRS of bank i from period t to period t+1.

$\Delta SE_i^{t,t+1}$: The “scale efficiency change”, of bank i‘s distance function of constant returns to scale (CRS) with its VRS distance function from period t to period t+1.

$\Delta T_{BCC,i}^{t,t+1}$: The “technical change under VRS” of bank i from period t to period t+1.

$\Delta S_i^{t,t+1}$: The “residual index of scale change under VRS” of bank i from period t to period t+1.

$Time$: Dummy variable of time, $Time = 1,2,3,....10(Year1993 = 1,.......2002 = 10)$

$\varphi_{i,t}, \varepsilon_{i,t}$: Residual term.

H_1^2 : Banks with a higher pure efficiency change ($\Delta PE_i^{t,t+1}$) will have a higher corporate value.

$$\log\left(\frac{V_{i,t}}{V_{i,t-1}}\right) = \alpha_{i,t} + Time + \beta_{i,t} * (\Delta PE_i^{t,t+1}) + \varepsilon_{i,t} \quad (2)$$

$H_1^2 : \beta_{i,t} \; 0$

H_1^3 : Banks with a higher scale efficiency change ($\Delta SE_i^{t,t+1}$) will have a higher corporate value.

$$\log\left(\frac{V_{i,t}}{V_{i,t-1}}\right) = \alpha_{i,t} + Time + \beta_{i,t} * (\Delta SE_i^{t,t+1}) + \varepsilon_{i,t} \quad (3)$$

H_1^4 : Banks with a higher technical change under VRS ($\Delta T_{BCC,i}^{t,t+1}$) will have a higher corporate value.

$$\log\left(\frac{V_{i,t}}{V_{i,t-1}}\right) = \alpha_{i,t} + Time + \beta_{i,t} * (\Delta T_{BCC,i}^{t,t+1}) + \varepsilon_{i,t} \quad (4)$$

H_1^5 : Banks with a higher residual index of scale change under VRS ($\Delta S_i^{t,t+1}$) will have a higher corporate value.

$$\log\left(\frac{V_{i,t}}{V_{i,t-1}}\right) = \alpha_{i,t} + Time + \beta_{i,t} * (\Delta S_i^{t,t+1}) + \varepsilon_{i,t} \quad (5)$$

If the test result accepts the hypotheses above, then there exists a correlation between a bank’s productivity change and its corporate value. A positive/negative sign is used to denote whether such correlation is positive or negative, and a regression coefficient is employed to determine the interaction between productivity change and corporate value.

To verify the study hypotheses, this study first applied Frontier Analysis to solve the linear equations so as to measure the technical efficiency scores under CRS and VRS as well as compute the scale efficiency scores and the scores of the four decomposed productivity change indexes. Finally, the study undertook panel estimation using EViews Random Effect program to examine the relationship between the four decomposed efficiency and corporate values.

Definition of variables

This study mainly applied DEA to define and measure technology and the yearly efficiencies of banks in nine Eastern-Asia countries (Japan, Taiwan, Indonesia, Hong Kong, Thailand, Malaysia, Philippines, Singapore, and Korea) from 1993 to 2002. To measure the production functions of the banks, this study adopted the input and output variables suggested and used by Gascón et al. (2002). Those variables are consistent with the inputs and outputs covered under the intermediation approach of Jemric and Vujcic (2002). Ataullah et al. (2004) have also used the following input and output variables to measure technical efficiency based on the loan-based model proposed by Bhattacharyya et al. (1997) and the income-based model proposed by Leightner and Lovell (1998).

Input variables for measuring productivity change

Including net property, plant and equipment, salaries and benefit expenses, other operating expense and total deposits:

Net property, plant and equipment: The net property, plant and equipment less accumulated depreciation, which is a stock variable.

Salaries and benefit expenses: “Salaries” plus “benefit expenses” are used as a proxy for the number of employees, which is a flow variable.

Other operating expense: All other non-operating expenses, which is a flow variable.

Total deposits: Aggregate total deposits. “Total deposits” has been used as an input variable by Humphrey (1991), English et al.(1993), Lang and Welzel (1996), Adam et al. (1999): Alam (2001) and is a stock variable.

Output variables for measuring productivity change

The output variables for measuring productivity change include total

Table 1. Numbers of public listed bank in 9 Eastern-Asia countries during the period of Asian financial crisis.

Country	Japan	Taiwan	Indonesia	Hong Kong	Thailand	Malaysia	Philippine	Singapore	Korea	Total
Numbers of bank	92	31	10	18	13	16	17	7	16	220

Table 2. Statistics summary for 9 Eastern-Asia countries during the period of the Asian financial crisis.

Variables	Net property, plant and equipment (X_1)	Salaries and benefit expenses (X_2)	Other operating expenses (X_3)	Total deposits (X_4)	Total investments (Y_1)	Total loans (Y_2)	Non-interest income plus other operating income (Y_3)
Obs.	2131	2131	2131	2131	2131	2131	2131
Mean	486350.66	303071.54	636305.18	21581570.25	8250012.33	19868146.78	247672.21
Median	212566.63	97831.43	50634.02	8168633.41	1645882.00	8198111.73	32717.69
Maximum	9425896.31	38049160.27	187467276.06	572235799.41	598686667.01	388665464.11	26425485.92
Minimum	0.01	0.00	-87413586.09	0.00	0.00	0.00	-373300.98
Std. Dev.	872324.33	1995939.49	8102294.24	52318064.93	30958492.36	43439453.80	1242042.20
Skewness	4.49	14.83	15.03	5.87	9.90	5.16	12.59
Kurtosis	28.67	232.69	297.27	45.00	133.75	32.62	194.31
Jarque Bera	65690.81	4762410.88	7769231.82	168864.92	1552828.28	87383.80	3305923.51
P-value	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***

Note: (1) These variables, according to January 1, 1993 the dollar exchange rate conversion, and therefore in United States dollars. Furthermore, in this study, in 1992 the consumer price index (CPI) by deflating is to eliminate the effects of changes in inflation. (2) ***Significantly at 1%; **Significantly at 5%; Significantly at 10%.

investments, total loans and non-interest income, plus other operating income.

Total investments: This is a stock variable.

Total loans: This is a stock variable.

Non-interest income plus other operating income: This is a flow variable.

The input and output variables were converted to USD based on the NTD: USD exchange rate on January 1, 1993, to prevent exchange rate fluctuation from affecting the measurement of the Malmquist indices. The study also used 1992 as the base year to deflate values using the 1992 CPI, so as to eliminate the influence of inflation change.

Data source and sampling

This study targeted all listed banks in nine Eastern-Asia countries (Japan, Taiwan, Indonesia, Hong Kong, Thailand, Malaysia, Philippines, Singapore and Korea) with complete input and output data from 1993 to 2002, and compared the technical efficiency and productivity indices of banks in each country before (1993 to 1997) and after (1998 to 2002) the Asian financial crisis. Bank data, including balance sheets, income statements and year-end closing stock prices were obtained through Compustat, Datastream and the Taiwan Economic Journal. Table 1 presents the number of valid samples with complete input and output data among all listed banks in nine Eastern-Asia countries (Table 1).

EMPIRICAL RESULTS

Efficiency and productivity change

Table 2 illustrates the descriptive statistics of bank variables in nine Eastern-Asia countries. There were a total of 2,131 observations on listed banks in the countries during 1993 to 2002. The total deposits showed the highest degree of variation, while net property, plant and equipment have the lowest. Because DEA efficiency scores are relative values, after observing the yearly evolution

Table 3. Cross-period comparison of technical efficiency and productivity change in 9 Eastern-Asian countries: Comparison of pre- and post- Asia financial crisis.

Country	Period	Relative Productivity under CCR DC_i^t	Relative Productivity under BCC DV_i^t	Residual Scale Efficiency SE_i^t	Malmquist Productivity Index	$\Delta PE_i^{t,t+1}$	$\Delta SE_i^{t,t+1}$	$\Delta T_{BCC,i}^{t,t+1}$	$\Delta S_i^{t,t+1}$
	1993~2002	97.8724	98.5620	0.9820	1.0603	1.0005	1.0069	1.0450	1.0072
Japan	1993~1997	97.4847	97.7260	0.9976	1.0061	1.0001	1.0004	1.0170	0.9888
	1998~2002	98.3394	98.7626	0.9957	1.0084	1.0001	1.0069	1.0143	0.9873
	1993~2002	98.3394	98.7626	0.9957	1.1499	1.0886	1.0094	1.0433	1.0030
Taiwan	1993~1997	97.7178	98.7005	0.9896	1.1573	1.1213	1.0054	1.0293	0.9973
	1998~2002	98.6246	128.2766	0.9939	1.0480	1.0113	0.9995	1.0357	1.0011
	1993~2002	93.5280	96.8575	0.9629	1.0083	1.0135	1.0020	0.9865	1.0065
Indonesia	1993~1997	98.7817	99.8360	0.9894	1.0321	1.0018	1.0078	1.0311	0.9914
	1998~2002	96.9665	99.7460	0.9720	1.1059	1.0001	1.0180	1.0419	1.0426
	1993~2002	91.6296	92.9021	0.9313	1.0113	1.0017	1.0013	1.0070	1.0013
Hong Kong	1993~1997	98.4227	99.4166	0.9898	0.9971	1.0010	1.0010	0.9928	1.0023
	1998~2002	99.0204	99.9314	0.9909	1.0535	1.0000	1.0031	1.0532	0.9972
	1993~2002	97.9143	99.2240	0.9866	1.0061	0.9995	1.0092	0.9997	0.9977
Thailand	1993~1997	99.6400	99.9735	0.9967	1.0505	1.0003	1.0084	1.0409	1.0005
	1998~2002	98.9865	99.6043	0.9938	0.9359	1.0000	1.0000	0.9393	0.9964
	1993~2002	97.7460	99.4523	0.9827	1.0565	0.9995	1.0092	1.0538	0.9939
Malaysia	1993~1997	98.7219	99.7451	0.9897	1.0894	1.0003	1.0084	1.0906	0.9903
	1998~2002	93.6379	93.6873	0.9370	0.9664	1.0000	1.0000	0.9664	1.0000
	1993~2002	98.3724	99.7901	0.9858	0.9991	0.9986	1.0042	0.9983	0.9980
Philippine	1993~1997	99.1449	99.9918	0.9915	0.7865	1.0000	1.0002	0.8970	0.8766
	1998~2002	99.5540	99.8081	0.9974	0.8697	0.9952	1.0064	0.9208	0.9430
	1993~2002	96.4686	98.1518	0.9827	1.1029	1.0008	0.9993	1.0986	1.0038
Singapore	1993~1997	98.1157	98.7033	0.9937	0.9900	1.0018	1.0018	0.9885	0.9979
	1998~2002	99.4823	99.9227	0.9956	1.2953	1.0000	1.0061	1.2905	0.9976
	1993~2002	97.3910	99.6262	0.9774	1.0945	1.0003	1.0096	1.0838	1.0000
Korea	1993~1997	99.1958	100.0000	0.9920	1.1679	1.0000	1.0041	1.1675	0.9963
	1998~2002	99.5995	99.9561	0.9964	1.0291	1.0000	1.0024	1.0300	0.9967

of the banks' technical efficiencies, it was found that if the average efficiency score of the banks in the current year was higher than that of the previous year, the average efficiency of the banks had improved relative to the benchmark bank. However, this does not necessarily mean that the efficiency of the overall banking industry had improved. Thus, year -to-year comparisons do not produce highly meaningful information. For that reason, an analysis of those results was omitted. Table 3 depicts the cross-period comparisons of technical efficiencies of banks before and after the Asian financial crisis.

In summary, of the nine sampled Eastern-Asia countries, countries whose banks experienced improved overall technical efficiency under the CRS and CRS models include: Japan, Taiwan, Hong Kong, Philippines, Singapore, and Korea. The improvements were largely attributed to an improved "scale efficiency change ($\Delta SE_i^{t,t+1}$)", "technical change under VRS ($\Delta T_{BCC,i}^{t,t+1}$)" and "residual index of scale change under VRS ($\Delta S_i^{t,t+1}$)." In contrast, the overall technical efficiency of banks in Indonesia, Thailand, and Malaysia declined after the Asian financial crisis, suggesting that the banking sector in those three countries was adversely affected by the Asian financial crisis, which led to a downturn of the operating efficiency of the banks. It is reasonable to assert that the Asian financial crisis not only caused currency depreciation and economic decline in Indonesia, Thailand, and Malaysia; it also adversely impacted the operating efficiency of their financial intermediaries. The common cause of decline in the overall technical efficiency of banks in these three countries could be attributed to a decline in the "pure efficiency change ($\Delta PE_i^{t,t+1}$)." In addition, sources of the decline in the overall technical efficiency of banks in Thailand also included a decline in the "scale efficiency change ($\Delta SE_i^{t,t+1}$)", "technical change under VRS ($\Delta T_{BCC,i}^{t,t+1}$)" and "residual index of scale change under VRS ($\Delta S_i^{t,t+1}$)". Additional sources of decline in the overall technical efficiency of banks in Malaysia also included a decline in the "scale efficiency change ($\Delta SE_i^{t,t+1}$)" and "technical change under VRS ($\Delta T_{BCC,i}^{t,t+1}$)."

A cross-country comparison of changes in the Malmquist productivity indexes found the following: the Malmquist indexes of Japanese and Indonesian banks exhibited identical variation trends. After the Asian financial crisis, the common factor bringing about an increase in the Malmquist indexes of both countries was an improvement in the "scale efficiency change ($\Delta SE_i^{t,t+1}$)". The Malmquist indexes of Taiwanese and Korean banks exhibited identical variation trends. After the Asian financial crisis, the common factor bringing about a decrease in the Malmquist indexes of both countries was a decline in the "scale efficiency change ($\Delta SE_i^{t,t+1}$)". The Malmquist indexes of Hong Kong and Singaporean banks exhibited identical variation trends. After the Asian financial crisis, the common factors bringing about an increase in the Malmquist indexes of both countries were improvements in the "scale efficiency change ($\Delta SE_i^{t,t+1}$)" and "technical change under VRS ($\Delta T_{BCC,i}^{t,t+1}$)". The Malmquist indexes of Thai and Malaysian banks exhibited identical variation trends. After the Asian financial crisis, the common factors bringing about a decrease in the Malmquist indexes of both countries were a decline in the "pure efficiency change ($\Delta PE_i^{t,t+1}$)", "scale efficiency change ($\Delta SE_i^{t,t+1}$)" and "technical change under VRS ($\Delta T_{BCC,i}^{t,t+1}$)."

In general, "scale efficiency change ($\Delta SE_i^{t,t+1}$)", "technical change under VRS ($\Delta T_{BCC,i}^{t,t+1}$)" and "residual index of scale change under VRS ($\Delta S_i^{t,t+1}$)" were important factors that prompted changes in the overall technical efficiencies of banks in Eastern-Asia countries before and after the Asian financial crisis (Table 3).

Relationship between efficiency, productivity change and corporate value

Tables 4 to 12 present the analysis of correlations between technical efficiency indexes and corporate values of banks in nine Eastern-Asia countries. Before the Asian financial crisis (1993 to 1997), the corporate value of banks in Japan, Thailand, Philippines and Korea all decremented significantly over time, reaching a 1% level, indicating that the value of banks in those countries declined each year during 1993 to 1997 (Tables 4, 8, 10, and 12). Banks in Taiwan showed a rise in the "technical change under VRS ($\Delta T_{BCC,i}^{t,t+1}$)" and their corporate value incremented significantly, reaching a 1% level, suggesting a strong positive relationship between the corporate value of Taiwanese banks and their "technical change under VRS ($\Delta T_{BCC,i}^{t,t+1}$)" (Table 5). Banks in Indonesia, improved their "pure efficiency change ($\Delta PE_i^{t,t+1}$)" and their corporate value decremented significantly, reaching a 5% level, which is consistent with the trends observed over the period 1993 to 2002 (Table 6). Banks in Singapore showed their "pure efficiency change ($\Delta PE_i^{t,t+1}$)" improved and their corporate value incremented significantly, reaching a 10% level, suggesting a strong positive relationship between corporate value and the "pure efficiency change ($\Delta PE_i^{t,t+1}$)" (Table 11). Lastly, banks in Korea showed an increase in the "scale efficiency change ($\Delta SE_i^{t,t+1}$)" and "residual index of scale change under VRS ($\Delta S_i^{t,t+1}$)", and their corporate value exhibited a significantly increasing trend, reaching a 5% level, suggesting a strong positive relationship between the corporate value, the "scale efficiency change ($\Delta SE_i^{t,t+1}$)" and the "residual index of scale change under VRS ($\Delta S_i^{t,t+1}$)." However, the corporate value of banks in Korea showed a significant negative relationship with their "technical change under VRS ($\Delta T_{BCC,i}^{t,t+1}$)", reaching a 5% level (Table 12), indicating that the "technical change under VRS ($\Delta T_{BCC,i}^{t,t+1}$)" was the primary factor in the decline in the corporate value of Korean banks. With respect to the technical efficiency scores of banks in other countries, their relationships with the corporate value of banks during 1993 to 1997 did not reach a significant level.

After the Asian financial crisis (1998 to 2002), the corporate value of banks in Taiwan all incremented

Table 4. Relationship between efficiency, productivity change and corporate value for banks: Japan.

Japan	Random effect	$\log(\frac{V_{i,t}}{V_{i,t-1}})$	$\Delta PE_i^{t,t+1}$	$\Delta SE_i^{t,t+1}$	$\Delta T_{BCC,i}^{t,t+1}$	$\Delta S_i^{t,t+1}$
Full Period (1993~2002)	C	-3.101990 (0.6053)	0.298397 (0.1717)	-0.162949 (0.6227)	-0.027686 (0.1104)	0.076774 (0.8087)
	Time	0.001097 (0.6428)	0.001052 (0.6539)	0.000914 (0.6974)	-0.000882 (0.7074)	0.000979 (0.6782)
	$\Delta PE_i^{t,t+1}$	-0.335914 (0.1268)	-0.329451 (0.1314)	--	--	--
	$\Delta SE_i^{t,t+1}$	1.820812 (0.5522)	--	0.132438 (0.6883)	--	--
	$\Delta T_{BCC,i}^{t,t+1}$	-0.002002 (0.7937)	--	--	-0.002414 (0.7521)	--
	$\Delta S_i^{t,t+1}$	1.587359 (0.5895)	--	--	--	-0.107515 (0.7348)
	R^2	0.006724	0.005260	0.000655	0.000522	0.000600
	Adjusted R^2	-0.003268	0.001289	-0.003334	-0.003468	-0.003397
	Durbin-Watson stat	2.648079	2.647580	2.647660	2.647613	2.649170
Pre- Asian Financial Crisis (1993~1997)	C	9.842630 (0.6974)	0.234244 (0.4066)	-0.466527 (0.4627)	0.102207 (0.0063***)*)	0.706054 (0.2747)
	Time	-0.042703 (0.0000***)	-0.042766 (0.0000***)	-0.042573 (0.0000***)	-0.043213 (0.0000***)	-0.042593 (0.0000***)
	$\Delta PE_i^{t,t+1}$	-0.149399 (0.6013)	-0.126080 (0.6549)	--	--	--
	$\Delta SE_i^{t,t+1}$	-4.433973 (0.7229)	--	0.573255 (0.3646)	--	--
	$\Delta T_{BCC,i}^{t,t+1}$	0.005335 (0.8136)	--	--	0.007164 (0.7490)	--
	$\Delta S_i^{t,t+1}$	-5.156676 (0.6872)	--	--	--	-0.599161 (0.3548)
	R^2	0.127499	0.122371	0.125213	0.121927	0.125368
	Adjusted R^2	0.107488	0.114429	0.117296	0.113980	0.117453
	Durbin-Watson stat	2.831559	2.817917	2.828962	2.821082	2.829449
Post- Asian Financial Crisis (1998~2002)	C	-0.113915 (0.9859)	0.526382 (0.1248)	0.088985 (0.8127)	0.017744 (0.6997)	-0.064992 (0.8543)

Table 4. Contd.

	Time	-0.002156 (0.7005)	-0.002227 (0.6854)	-0.003104 (0.5722)	-0.003249 (0.5550)	-0.002905 (0.5992)
	$\Delta PE_i^{t,t+1}$	-0.509356 (0.1467)	-0.519762 (0.1312)	--	--	--
	$\Delta SE_i^{t,t+1}$	0.312753 (0.9248)	--	-0.075868 (0.8390)	--	--
	$\Delta T_{BCC,i}^{t,t+1}$	-0.001922 (0.8075)	--	--	-0.003181 (0.6837)	--
	$\Delta S_i^{t,t+1}$	0.318712 (0.9183)	--	--	--	0.076695 (0.8270)
	R^2	0.010813	0.010605	0.001487	0.001998	0.001336
	Adjusted R^2	-0.007304	0.003461	-0.005723	-0.005207	-0.005901
	Durbin-Watson stat	2.567132	2.56705	2.569927	2.573005	2.573355

Table 5. Relationship between efficiency, productivity change and corporate value for banks: Taiwan.

Taiwan	**Random effect**	$\log(\frac{V_{i,t}}{V_{i,t-1}})$	$\Delta PE_i^{t,t+1}$	$\Delta SE_i^{t,t+1}$	$\Delta T_{BCC,i}^{t,t+1}$	$\Delta S_i^{t,t+1}$
Full Period (1993~2002)	C	0.084963 (0.6802)	0.054836 (0.0358**)	0.068190 (0.4089)	0.029148 (0.4235)	0.055616 (0.4621)
	Time	-0.009803 (0.0095***)	-0.009877 (0.0086***)	-0.010109 (0.0070***)	-0.010034 (0.0073***)	-0.010093 (0.0071***)
	$\Delta PE_i^{t,t+1}$	0.006009 (0.3782)	0.004525 (0.4996)	--	--	--
	$\Delta SE_i^{t,t+1}$	-0.051853 (0.6597)	--	-0.006971 (0.9285)	--	--
	$\Delta T_{BCC,i}^{t,t+1}$	0.037043 (0.1748)	--	--	0.030367 (0.2394)	--
	$\Delta S_i^{t,t+1}$	-0.018356 (0.8606)	--	--	--	0.005445 (0.9388)
	R^2	0.035891	0.028949	0.027291	0.032377	0.027283
	Adjusted R^2	0.018234	0.021913	0.020243	0.025365	0.020235
	Durbin-Watson stat	1.907777	1.912478	1.900203	1..904310	1.900715
Pre- Asian Financial Crisis (1993~1997)	C	-0.099096 (0.7978)	0.080628 (0.0537*)	0.044643 (0.6731)	0.015679 (0.7307)	0.10404 (0.3460)

Table 5. Contd.

	Time	-0.009358 (0.3835)	-0.006093 (0.5779)	-0.006908 (0.5254)	-0.010445 (0.3241)	-0.006843 (0.5293)
	$\Delta PE_i^{t,t+1}$	0.00646 (0.2543)	0.003347 (0.5561)	--	--	--
	$\Delta SE_i^{t,t+1}$	0.0208 (0.9150)	--	0.0422 (0.6639)	--	--
	$\Delta T_{BCC,i}^{t,t+1}$	0.089426 (0.0027***)	--	--	0.081598 (0.0037***)	--
	$\Delta S_i^{t,t+1}$	0.074241 (0.7156)	--	--	---	-0.01683 (0.8699)
	R^2					
	Adjusted R^2	0.096157	0.007143	0.005622	0.082412	0.004062
	Durbin-Watson stat	0.057859	-0.009268	-0.010814	0.067245	-0.0124
		3.171018	3.136493	3.114055	3.143464	3.10485
Post- Asian Financial Crisis (1998~2002)	C	-0.513113 (0.0467**)	-0.365759 (0.0149**)	-0.39542 (0.0005***)	-0.526937 (0.0000***)	-0.60587 (0.0000***)
	Time	0.058138 (0.0000***)	0.056244 (0.0000***)	0.056208 (0.0000***)	0.056884 (0.0000***)	0.057106 (0.0000***)
	$\Delta PE_i^{t,t+1}$	-0.019897 (0.9191)	-0.133403 (0.3295)	--	--	--
	$\Delta SE_i^{t,t+1}$	-0.065228 (0.6860)	--	-0.103522 (0.2621)	--	--
	$\Delta T_{BCC,i}^{t,t+1}$	0.026331 (0.5063)	--	--	0.02117 (0.5637)	--
	$\Delta S_i^{t,t+1}$	0.056195 (0.6043)	--	--	--	0.099188 (0.2005)
	R^2	0.260389	0.252151	0.253766	0.247306	0.255577
	Adjusted R^2	0.23557	0.242311	0.243947	0.237402	0.245782
	Durbin-Watson stat	2.245308	2.213394	2.200609	2.226606	2.204563

significantly over time, reaching a 1% level, indicating a gradual rise in the corporate value of banks after the crisis (Table 5). Banks in Hong Kong showed an increase in the “scale efficiency change ($\Delta SE_i^{t,t+1}$)” and “residual index of scale change under VRS ($\Delta S_i^{t,t+1}$)”, and the corporate value of the banks decremented significantly, reaching a 10% level (Table 7). Banks in Malaysia showed an increase in the “technical change under VRS ($\Delta T_{BCC,i}^{t,t+1}$)” and their corporate value decremented significantly, reaching a 1% level (10%). However, banks in The Philippines showed an increase in the “pure efficiency change ($\Delta PE_i^{t,t+1}$)” and their corporate values incremented significantly, reaching a 5% level, suggesting a strong positive relationship between the corporate value of Philippine banks and their “pure efficiency change ($\Delta PE_i^{t,t+1}$)” (Table 10). Banks in Korea showed

Table 6. Relationship between efficiency, productivity change and corporate value for banks: Indonesia.

Indonesian	**Fixed effect**	$\log(\frac{V_{i,t}}{V_{i,t-1}})$	$\Delta PE_i^{t,t+1}$	$\Delta SE_i^{t,t+1}$	$\Delta T_{BCC,i}^{t,t+1}$	$\Delta S_i^{t,t+1}$
Full Period (1993~2002)	C	-6.427567 (0.1846)	1.428653 (0.0452**)	-0.445758 (0.5850)	0.408057 (0.3160)	0.675640 (0.3429)
	Time	-0.039216 (0.4288)	-0.014240 (0.7550)	-0.035723 (0.4332)	-0.034780 (0.4534)	-0.032286 (0.4875)
	$\Delta PE_i^{t,t+1}$	-1.563755 (0.0354**)	-1.202684 (0.0889*)	--	--	--
	$\Delta SE_i^{t,t+1}$	5.054288 (0.0583*)	--	0.788963 (0.3070)	--	--
	$\Delta T_{BCC,i}^{t,t+1}$	-0.026831 (0.9252)	--	--	-0.078651 (0.7887)	--
	$\Delta S_i^{t,t+1}$	3.267115 (0.1374)	--	--	--	-0.346684 (0.5966)
	R^2	0.277071	0.119273	0.062286	0.030887	0.037707
	Adjusted R^2	0.062870	-0.027515	-0.094000	-0.130632	-0.122675
	Durbin-Watson stat	2.463701	2.713163	2.658534	2.756911	2.706230
Pre- Asian Financial Crisis (1993~1997)	C	-96.46722 (0.6862)	57.27882 (0.0140**)	-3.116803 (0.5208)	0.365016 (0.5797)	3.288576 (0.5252)
	Time	0.120413 (0.3813)	0.080034 (0.4576)	0.005384 (0.9705)	0.066132 (0.6544)	0.00414 (0.9775)
	$\Delta PE_i^{t,t+1}$	-59.90454 (0.0204**)	-57.39835 (0.0141**)	--	--	--
	$\Delta SE_i^{t,t+1}$	79.84505 (0.5087)	--	3.255723 (0.5116)	--	--
	$\Delta T_{BCC,i}^{t,t+1}$	-0.164288 (0.7716)	--	--	-0.428166 (0.4482)	--
	$\Delta S_i^{t,t+1}$	76.34765 (0.5300)	--	--	--	-3.141786 (0.5296)
	R^2	0.613347	0.474815	0.055541	0.069747	0.05199
	Adjusted R^2	0.171457	0.212222	-0.416688	-0.395379	-0.422014
	Durbin-Watson stat	3.166297	2.793599	3.325551	3.402005	3.311878
Post- Asian Financial Crisis (1998~2002)	C	-9.418592 (0.2131)	1.776785 (0.1338)	0.646839 (0.6379)	1.384782 (0.2260)	1.858306 (0.2030)
	Time	-0.185003 (0.3358)	-0.084767 (0.5802)	-0.172736 (0.2104)	-0.177169 (0.2332)	-0.163608 (0.2411)

Table 6. Contd.

	$\Delta PE_i^{t,t+1}$	-1.002798 (0.3684)	-0.979127 (0.3119)	--	--	--
	$\Delta SE_i^{t,t+1}$	6.790093 (0.1076)	--	0.840395 (0.3766)	--	--
	$\Delta T_{BCC,i}^{t,t+1}$	0.29441 (0.5723)	--	--	0.137099 (0.7590)	--
	$\Delta S_i^{t,t+1}$	4.755528 (0.1763)	--	--	--	-0.428755 (0.6038)
	R^2	0.401371	0.177953	0.163184	0.119496	0.130838
	Adjusted R^2	-0.033996	-0.115636	-0.135679	-0.194969	-0.179577
	Durbin-Watson stat	2.249667	2.902453	2.895944	3.025984	2.970112

Note: Because of "all of the banks (cross data number)" below "the number of explanatory variables" in Indonesia, which cannot be implemented random effect, and therefore the implementation of the fixed effect.

Table 7. Relationship between efficiency, productivity change and corporate value for banks: Hong Kong.

Hong Kong	Random effect	$\log(\frac{V_{i,t}}{V_{i,t-1}})$	$\Delta PE_i^{t,t+1}$	$\Delta SE_i^{t,t+1}$	$\Delta T_{BCC,i}^{t,t+1}$	$\Delta S_i^{t,t+1}$
Full Period (1993~2002)	C	6.717322 (0.6475)	-0.041571 (0.8709)	0.197926 (0.6471)	-0.026829 (0.6746)	0.270759 (0.5432)
	Time	-0.002724 (0.6605)	-0.001788 (0.7572)	-0.002026 (0.7256)	-0.002942 (0.6196)	-0.002060 (0.7205)
	$\Delta PE_i^{t,t+1}$	0.024328 (0.9285)	0.056655 (0.8262)	--	--	--
	$\Delta SE_i^{t,t+1}$	-3.274065 (0.4412)	--	0.214402 (0.6228)	--	--
	$\Delta T_{BCC,i}^{t,t+1}$	0.045548 (0.4876)	--	--	0.049925 (0.4340)	--
	$\Delta S_i^{t,t+1}$	-3.487667 (0.4153)	--	--	--	-0.253804 (0.5629)
	R^2	0.027736	0.002245	0.005692	0.012178	0.007344
	Adjusted R^2	-0.057550	-0.031014	-0.027451	-0.020750	-0.025744
	Durbin-Watson stat	2.183852	2.174081	2.148044	2.150660	2.149672
Pre- Asian Financial Crisis (1993~1997)	C	-16.05084 (0.5430)	0.483453 (0.4115)	0.041774 (0.9696)	-0.078006 (0.6040)	-0.136583 (0.9006)
	Time	0.01856 (0.4858)	0.023313 (0.4127)	0.01367 (0.6220)	0.011281 (0.6705)	0.013873 (0.6153)

Table 7. Contd.

	$\Delta PE_i^{t,t+1}$	-0.708778 (0.2467)	-0.54997 (0.3759)	--	--	--
	$\Delta SE_i^{t,t+1}$	8.561977 (0.5269)	--	-0.075216 (0.9464)	--	--
	$\Delta T_{BCC,i}^{t,t+1}$	0.126102 (0.3747)	--	--	0.057507 (0.6877)	--
	$\Delta S_i^{t,t+1}$	8.025349 (0.5329)	--	--	--	0.102358 (0.9231)
	R^2	0.088629	0.049936	0.012414	0.020001	0.012651
	Adjusted R^2	-0.118501	-0.02607	-0.066593	-0.058399	-0.066337
	Durbin-Watson stat	2.031332	2.253103	2.33022	2.293604	2.332988
Post- Asian Financial Crisis (1998~2002)	C	14.45396 (0.0755*)	-0.255474 (0.3427)	-0.238277 (0.5854)	-0.048499 (0.6535)	0.328667 (0.5171)
	Time	-0.004031 (0.7395)	-0.001104 (0.9274)	-0.000158 (0.9899)	0.000141 (0.9907)	-0.000747 (0.9518)
	$\Delta PE_i^{t,t+1}$	0.301886 (0.2589)	0.260317 (0.3444)	--	--	--
	$\Delta SE_i^{t,t+1}$	-7.181203 (0.0741*)	--	0.235871 (0.6044)	--	--
	$\Delta T_{BCC,i}^{t,t+1}$	0.063757 (0.3255)	--	--	0.042678 (0.5289)	--
	$\Delta S_i^{t,t+1}$	-7.601389 (0.0670*)	--	--	--	-0.325957 (0.4872)
	R^2	0.171943	0.03323	0.010667	0.01534	0.018474
	Adjusted R^2	0.029175	-0.027193	-0.051166	-0.046201	-0.042871
	Durbin-Watson stat	2.653291	2.590507	2.388951	2.481551	2.379333

Table 8. Relationship between efficiency, productivity change and corporate value for banks: Thailand.

Thailand	Random effect	$\log(\frac{V_{i,t}}{V_{i,t-1}})$	$\Delta PE_i^{t,t+1}$	$\Delta SE_i^{t,t+1}$	$\Delta T_{BCC,i}^{t,t+1}$	$\Delta S_i^{t,t+1}$
ull Period (1993~2002)	C	0.590964 (0.9859)	0.446255 (0.8043)	1.010395 (0.4916)	0.220152 (0.7068)	-0.798667 (0.5940)
	Time	-0.016461 (0.4949)	-0.018050 (0.4267)	-0.016422 (0.4699)	-0.017923 (0.4296)	-0.016119 (0.4789)
	$\Delta PE_i^{t,t+1}$	-0.582873 (0.7578)	-0.327868 (0.8548)	--	--	--
	$\Delta SE_i^{t,t+1}$	-0.441236 (0.9787)	--	-0.899857 (0.5412)	--	--

Table 8. Contd.

	$\Delta T^{t,t+1}_{BCC,i}$	-0.013616 (0.9825)	--	--	-0.105203 (0.8565)	--
	$\Delta S^{t,t+1}_{i}$	0.555261 (0.9733)	--	--	--	0.905965 (0.5390)
	R^2 Adjusted R^2 Durbin-Watson stat	0.022417 -0.079415 1.839813	0.013378 -0.025313 1.863552	0.020286 -0.018134 1.835682	0.013362 -0.025330 1.849287	0.020363 -0.018054 1.831026
Pre- Asian Financial Crisis (1993~1997)	C	30.83647 (0.5960)	0.610868 (0.8211)	0.886459 (0.6631)	0.273817 (0.7518)	0.987459 (0.6418)
	Time	-0.277188 (0.0117**)	-0.250408 (0.0081***)	-0.248738 (0.0079***)	-0.266696 (0.0054***)	-0.249828 (0.0078***)
	$\Delta PE_i^{t,t+1}$	-0.216568 (0.9540)	0.239406 (0.9303)	--	--	--
	$\Delta SE_i^{t,t+1}$	-15.29459 (0.5871)	--	-0.041902 (0.9837)	--	--
	$\Delta T^{t,t+1}_{BCC,i}$	0.611155 (0.5893)	--	--	0.64335 (0.4817)	--
	$\Delta Si^{t,t+1}$	-14.9503 (0.5906)	--	--	--	-0.138676 (0.9459)
	R^2 Adjusted R^2 Durbin-Watson stat	0.351547 0.171421 1.529823	0.303703 0.237389 1.488078	0.298255 0.231423 1.444455	0.323884 0.259492 1.453856	0.303444 0.237105 1.486119
Post- Asian Financial Crisis (1998~2002)	C	-46.10919 (0.4756)	-0.368585 (0.8633)	1.605396 (0.3976)	0.251944 (0.7204)	-0.949486 (0.6346)
	Time	-0.0359 (0.4605)	-0.046962 (0.2943)	-0.044854 (0.3149)	-0.050954 (0.2593)	-0.043941 (0.3248)
	$\Delta PE_i^{t,t+1}$	0.089885 (0.9698)	0.787468 (0.7056)	--	--	--
	$\Delta SE_i^{t,t+1}$	22.34554 (0.4956)	--	-1.20279 (0.5268)	--	--
	$\Delta T^{t,t+1}_{BCC,i}$	0.062501 (0.9371)	--	--	0.204857 (0.7695)	--
	$\Delta Si^{t,t+1}$	23.92059 (0.4685)	--	--	--	1.343763 (0.4840)

Table 8. Contd.

	R^2	0.106905	0.058016	0.068885	0.055568	0.072612
	Adjusted R^2	-0.079156	-0.01176	-0.000087	-0.01439	0.003916
	Durbin-Watson stat	2.098564	2.16971	2.312809	2.211844	2.308032

Table 9. Relationship between efficiency, productivity change and corporate value for banks: Malaysia.

Malaysia	**Fixed Effect**	$\log(\frac{V_{i,t}}{V_{i,t-1}})$	$\Delta PE_i^{t,t+1}$	$\Delta SE_i^{t,t+1}$	$\Delta T_{BCC,i}^{t,t+1}$	$\Delta S_i^{t,t+1}$
Full Period (1993~2002)	C	3.547927 (0.6913)	0.869426 (0.6087)	-0.138424 (0.8084)	0.281818 (0.5193)	0.200553 (0.7792)
	Time	0.001336 (0.9549)	0.011696 (0.5766)	0.011629 (0.5937)	0.003327 (0.8833)	0.012122 (0.5732)
	$\Delta PE_i^{t,t+1}$	-1.077118 (0.5378)	-0.907072 (0.5951)	--	--	--
	$\Delta SE_i^{t,t+1}$	-0.131980 (0.9727)	--	0.098552 (0.8457)	--	--
	$\Delta T_{BCC,i}^{t,t+1}$	-0.716453 (0.2458)	--	--	-0.256803 (0.4533)	--
	$\Delta S_i^{t,t+1}$	-1.579544 (0.7605)	--	--	--	-0.244402 (0.7421)
	R^2	0.159776	0.060226	0.049478	0.072375	0.052586
	Adjusted R^2	-0.149781	-0.110642	-0.123344	-0.096284	-0.119672
	Durbin-Watson stat	2.748188	2.936588	2.930915	2.862883	2.919935
Pre- Asian Financial Crisis (1993~1997)	C	22.31948 (0.2911)	2.612386 (0.3693)	0.018454 (0.9852)	0.012298 (0.9880)	0.447101 (0.6588)
	Time	-0.127053 (0.3759)	-0.064909 (0.4932)	-0.053569 (0.6143)	-0.053429 (0.6054)	-0.050666 (0.6248)
	$\Delta PE_i^{t,t+1}$	-1.646688 (0.6370)	-2.436922 (0.3968)	--	--	--
	$\Delta SE_i^{t,t+1}$	-9.672552 (0.3421)	--	0.126327 (0.8673)	--	--
	$\Delta T_{BCC,i}^{t,t+1}$	1.3884 (0.4476)	--	--	0.123872 (0.8275)	--
	$\Delta S_i^{t,t+1}$	-12.01593 (0.3331)	--	--	--	-0.314999 (0.7714)

Table 9. Contd.

	R^2	0.410181	0.228585	0.142531	0.145097	0.149927
	Adjusted R^2	-0.622002	-0.212223	-0.347451	-0.34342	-0.335829
	Durbin-Watson stat	2.393056	2.611797	2.538292	2.607052	2.515816
Post- Asian Financial Crisis (1998~2002)	C	-334.5394 (0.6523)	0.302346 (0.9126)	9.419398 (0.1417)	2.356704 (0.0006***)	-8.58177 (0.1721)
	Time	-0.063734 (0.1322)	-0.031139 (0.4783)	-0.045179 (0.2687)	-0.074006 (0.0160**)	-0.044519 (0.2748)
	$\Delta PE_i^{t,t+1}$	0.461003 (0.8725)	0.033726 (0.9899)	--	--	--
	$\Delta SE_i^{t,t+1}$	167.8793 (0.6477)	--	-8.951647 (0.1545)	--	--
	$\Delta T_{BCC,i}^{t,t+1}$	-1.864368 (0.0227**)	--	--	-1.67832 (0.0010***)	--
	$\Delta S_i^{t,t+1}$	168.6419 (0.6521)	--	--	--	9.043544 (0.1569)
	R^2	0.721209	0.093631	0.267457	0.705408	0.265647
	Adjusted R^2	0.442417	-0.268917	-0.02556	0.587571	-0.028095
	Durbin-Watson stat	3.344614	3.46619	3.832959	3.259321	3.836198

Note: Because of "all of the banks (cross data number)" below "the number of explanatory variables" in Malaysia, which cannot be implemented random effect, and therefore the implementation of the fixed effect.

an increase in the "scale efficiency change ($\Delta SE_i^{t,t+1}$)" and their corporate value also incremented significantly (reaching a 10% level), suggesting a positive relationship between the corporate value of banks in Korea and their "scale efficiency change ($\Delta SE_i^{t,t+1}$)." However, the corporate value of Korean banks exhibited a negative relationship with their "residual index of scale change under VRS ($\Delta S_i^{t,t+1}$)", reaching a 10% level of significance (Table 12) . No significant relationships between the corporate value of banks and their technical efficiency scores in other countries over the period 1998 to 2002 were observed.

In summary, after the Asian financial crisis (1998 to 2002), "pure efficiency change ($\Delta PE_i^{t,t+1}$)" was the primary factor that prompted the corporate value of banks in the Philippines to grow, which is consistent with the empirical results of Gascón et al. (2002),. There is a positive relationship between "pure efficiency change ($\Delta PE_i^{t,t+1}$)" and market returns. It also implies that improvements in the pure efficiency of banks accom-pany a rise in corporate value. The index "scale efficiency change ($\Delta SE_i^{t,t+1}$)" was also a key factor bringing about the growth in the corporate value of Korean banks. These phenomena are identical to the situation that existed prior to the Asian financial crisis (1993~1997).

The results of this study show that before the Asian financial crisis (1993 to 1997), "pure efficiency change ($\Delta PE_i^{t,t+1}$)" and "technical change under VRS ($\Delta T_{BCC,i}^{t,t+1}$)" were important factors influencing the corporate value of banks. After the Asian financial crisis (1998 to 2002), "scale efficiency change ($\Delta SE_i^{t,t+1}$)" and "residual index of scale change under VRS ($\Delta S_i^{t,t+1}$)" were the key factors influencing the corporate value of banks (Tables 4 to 12).

Conclusion

This study carried out structural analysis and comparison of changes in the productivity of banks in nine Eastern-Asia countries, to find the correlation of productivity changes with corporate value. The results showed that

Table 10. Relationship between efficiency, productivity change and corporate value for banks: Philippine.

Philippine	**Random effect**	$\log(\frac{V_{i,t}}{V_{i,t-1}})$	$\Delta PE_i^{t,t+1}$	$\Delta SE_i^{t,t+1}$	$\Delta T_{BCC,i}^{t,t+1}$	$\Delta S_i^{t,t+1}$
Full Period (1993~2002)	C	-5.585478 (0.6861)	-1.845970 (0.5541)	0.423449 (0.6722)	0.684673 (0.0641)	-0.171164 (0.8909)
	Time	-0.028393 (0.2641)	-0.034249 (0.1610)	-0.033566 (0.1707)	-0.030465 (0.2112)	-0.033424 (0.1720)
	$\Delta PE_i^{t,t+1}$	1.883828 (0.5592)	2.063476 (0.5090)	--	--	--
	$\Delta SE_i^{t,t+1}$	2.466260 (0.6806)	--	-0.208090 (0.8307)	--	--
	$\Delta T_{BCC,i}^{t,t+1}$	-0.591392 (0.1982)	--	--	-0.482985 (0.1543)	--
	$\Delta S_i^{t,t+1}$	2.007110 (0.7972)	--	--	--	0.385707 (0.7566)
	R^2	0.184480	0.038322	0.031707	0.061653	0.032530
	Adjusted R^2	0.008583	0.006266	-0.000569	0.030374	0.000281
	Durbin-Watson stat	2.614920	2.228973	2.4213406	2.330093	2.214413
Pre- Asian Financial Crisis (1993~1997)	C	-4.554842 (0.7051)	0.672891 (0.7001)	0.676266 (0.2626)	0.590841 (0.0437**)	0.235491 (0.7633)
	Time	-0.109736 (0.0464**)	-0.119577 (0.0129**)	-0.120397 (0.0114**)	-0.115884 (0.0158**)	-0.120098 (0.0117**)
	$\Delta PE_i^{t,t+1}$	-0.574039 (0.7699)	-0.172074 (0.9218)	--	--	--
	$\Delta SE_i^{t,t+1}$	2.378932 (0.6537)	--	-0.170346 (0.7619)	--	--
	$\Delta T_{BCC,i}^{t,t+1}$	-0.111752 (0.7849)	--	--	-0.102870 (0.7012)	--
	$\Delta S_i^{t,t+1}$	3.320601 (0.6434)	--	--	--	0.269073 (0.7271)
	R^2	0.226896	0.223092	0.217101	0.218627	0.218004
	Adjusted R^2	0.051191	0.160939	0.154469	0.156117	0.155445
	Durbin-Watson stat	2.077238	1.979682	1.941771	2.015099	1.954804
Post- Asian Financial Crisis (1998~2002)	C	-77.10451 (0.2619)	-27.22713 (0.0477**)	1.031731 (0.7324)	0.843697 (0.3578)	-1.057038 (0.7451)
	Time	-0.047079 (0.5623)	-0.018004 (0.8073)	-0.010234 (0.8965)	-0.020199 (0.7954)	-0.009986 (0.8990)

Table 10. Cont'd

	$\Delta PE_i^{t,t+1}$	29.33199 (0.0447**)	27.30982 (0.0469**)	--	--	--
	$\Delta SE_i^{t,t+1}$	26.39155 (0.428)	--	-0.987886 (0.7449)	--	--
	$\Delta T_{BCC,i}^{t,t+1}$	-1.337208 (0.1207)	--	--	-0.706228 (0.2456)	--
	$\Delta S_i^{t,t+1}$	23.02324 (0.4879)	--	--	--	1.097803 (0.7234)
	R^2	0.207197	0.121695	0.004435	0.04485	0.005058
	Adjusted R^2	0.070507	0.066801	-0.057787	-0.014847	-0.057126
	Durbin-Watson stat	2.919977	2.467607	2.349492	2.603646	2.349092

Table 11. Relationship between efficiency, productivity change and corporate value for banks: Singapore

Singapore	Fixed effect	$\log(\frac{V_{i,t}}{V_{i,t-1}})$	$\Delta PE_i^{t,t+1}$	$\Delta SE_i^{t,t+1}$	$\Delta T_{BCC,i}^{t,t+1}$	$\Delta S_i^{t,t+1}$
Full Period (1993~2002)	C	-4.917181 (0.8148)	2.354833 (0.1925)	-0.762611 (0.3576)	-0.024264 (0.9165)	0.648041 (0.4102)
	Time	0.006785 (0.7857)	0.007268 (0.7317)	0.012874 (0.5456)	0.013982 (0.5542)	0.013096 (0.5399)
	$\Delta PE_i^{t,t+1}$	-1.981824 (0.3266)	-2.353254 (0.1884)	--	--	--
	$\Delta SE_i^{t,t+1}$	3.833290 (0.7174)	--	0.747841 (0.3644)	--	--
	$\Delta T_{BCC,i}^{t,t+1}$	-0.003357 (0.9891)	--	--	0.007099 (0.9762)	--
	$\Delta S_i^{t,t+1}$	3.063167 (0.7566)	--	--	--	-0.661611 (0.3924)
	R^2	0.169355	0.135702	0.083668	0.033800	0.078265
	Adjusted R^2	-0.277916	-0.080373	-0.145415	-0.207750	-0.152169
	Durbin-Watson stat	3.369241	3.327567	3.424005	3.330302	3.424295
Pre- Asian Financial Crisis (1993~1997)	C	-1.089784 (0.9263)	-2.80575 (0.0622*)	-0.175048 (0.7476)	0.515087 (0.2199)	0.180149 (0.6792)
	Time	0.011107 (0.7605)	-0.008986 (0.5999)	0.00409 (0.8609)	0.022623 (0.3991)	0.003988 (0.8645)
	$\Delta PE_i^{t,t+1}$	2.454773 (0.2395)	2.864321 (0.0601*)	--	--	--
	$\Delta SE_i^{t,t+1}$	-0.449256 (0.9446)	--	0.189439 (0.7095)	--	--

Table 11. Cont'd

	$\Delta T_{BCC,i}^{t,t+1}$	-0.431389 (0.4431)	--	--	-0.570516 (0.2345)	--
	$\Delta S_{i}^{t,t+1}$	-0.496931 (0.9311)	--	--	--	-0.165048 (0.7181)
	R^2	0.571112	0.485275	0.135136	0.288507	0.134016
	Adjusted R^2	-0.179443	0.191146	-0.359072	-0.118061	-0.360832
	Durbin-Watson stat	1.902613	1.775469	1.907597	1.937756	1.906148
Post- Asian Financial Crisis (1998~2002)	C	-150.3307 (0.8994)	4.816468 (0.3186)	-2.705435 (0.4540)	-0.02748 (0.9812)	2.4464 (0.4671)
	Time	0.290619 (0.8934)	-0.001528 (0.9914)	0.033864 (0.8230)	0.005056 (0.9807)	0.027994 (0.8521)
	$\Delta PE_{i}^{t,t+1}$	-6.255707 (0.7697)	-4.790805 (0.3038)	--	--	--
	$\Delta SE_{i}^{t,t+1}$	76.81988 (0.8962)	--	2.506402 (0.4415)	--	--
	$\Delta T_{BCC,i}^{t,t+1}$	-0.576516 (0.8903)	--	--	0.073715 (0.9119)	--
	$\Delta S_{i}^{t,t+1}$	78.16725 (0.8968)	--	--	--	-2.599429 (0.4352)
	R^2	0.283615	0.261496	0.1582	0.00838	0.162126
	Adjusted R^2	-4.731079	-0.477008	-0.683601	-0.98324	-0.675748
	Durbin-Watson stat	3.744781	3.79187	3.536335	3.850222	3.531005

Note: Because of "all of the banks (cross data number)" below "the number of explanatory variables" in Singapore, which cannot be implemented random effect, and therefore the implementation of the fixed effect.

Table 12. Relationship between efficiency, productivity change and corporate value for banks: Korea.

Korea	**Random effect**	$\log(\frac{V_{i,t}}{V_{i,t-1}})$	$\Delta PE_{i}^{t,t+1}$	$\Delta SE_{i}^{t,t+1}$	$\Delta T_{BCC,i}^{t,t+1}$	$\Delta S_{i}^{t,t+1}$
Full Period (1993~2002)	C	-0.476815 (0.9422)	-1.072363 (0.6736)	-0.148082 (0.8178)	-0.011831 (0.9402)	0.186382 (0.8163)
	Time	0.001868 (0.9334)	0.001595 (0.9400)	0.002542 (0.9045)	0.002692 (0.9000)	0.002217 (0.9165)
	$\Delta PE_{i}^{t,t+1}$	1.032108 (0.6936)	1.073973 (0.6738)	--	--	--
	$\Delta SE_{i}^{t,t+1}$	-0.159407 (0.9509)	--	0.143032 (0.8161)	--	--
	$\Delta T_{BCC,i}^{t,t+1}$	0.009346 (0.8740)	--	--	0.006285 (0.9004)	--
	$\Delta S_{i}^{t,t+1}$	-0.406404 (0.9047)	--	--	--	-0.188817 (0.8116)

Table 12. Contd.

	R^2	0.004052	0.002862	0.000999	0.000412	0.001041
	Adjusted R^2	-0.072560	-0.026465	-0.028384	-0.028987	-0.028341
	Durbin-Watson stat	2.255321	2.344474	2.364662	2.359449	2.365742
Pre- Asian Financial Crisis (1993~1997)	C	-2.059517 (0.1715)	1.112419 (0.2638)	0.355995 (0.0285**)	0.315056 (0.0000***)	0.116395 (0.5536)
	Time	-0.083236 (0.0000***)	-0.080165 (0.0000***)	-0.082116 (0.0000***)	-0.086540 (0.0000***)	-0.081463 (0.0000***)
	$\Delta PE_i^{t,t+1}$	-0.787780 (0.3722)	-0.837536 (0.4014)	--	--	--
	$\Delta SE_i^{t,t+1}$	1.284066 (0.0196**)	--	-0.073254 (0.6094)	--	--
	$\Delta T_{BCC,i}^{t,t+1}$	-0.029519 (0.0207**)	--	--	-0.013945 (0.2383)	--
	$\Delta S_i^{t,t+1}$	1.873290 (0.0109**)	--	--	--	0.163486 (0.3763)
	R^2	0.624615	0.491394	0.478068	0.494405	0.491109
	Adjusted R^2	0.552425	0.456318	0.442073	0.459537	0.456013
	Durbin-Watson stat	2.225282	2.566597	2.525094	2.558199	2.504555
Post- Asian Financial Crisis (1998~2002)	C	-165.2868 (0.5769)	-2.458135 (0.5709)	-8.464769 (0.0773*)	-0.567992 (0.4444)	7.930346 (0.0941*)
	Time	0.038458 (0.6103)	0.019772 (0.7859)	0.03226 (0.6385)	0.018446 (0.7994)	0.030922 (0.6530)
	$\Delta PE_i^{t,t+1}$	0.374018 (0.9325)	2.325759 (0.5949)	--	--	--
	$\Delta SE_i^{t,t+1}$	85.6959 (0.5612)	--	8.207758 (0.0812*)	--	--
	$\Delta T_{BCC,i}^{t,t+1}$	0.307844 (0.5433)	--	--	0.439313 (0.3890)	--
	$\Delta S_i^{t,t+1}$	78.56658 (0.5967)	--	--	--	-8.17305 (0.0853*)
	R^2	0.111301	0.012215	0.090086	0.026347	0.088132
	Adjusted R^2	-0.02335	-0.042662	0.039535	-0.027745	0.037472
	Durbin-Watson stat	2.416802	2.413644	2.443163	2.563187	2.451483

countries whose banks experienced improvements in overall technical efficiency after the Asian financial crisis include: Japan, Taiwan, Hong Kong, Philippines, Singapore and Korea, with the improved efficiency attributed to a rise in the "scale efficiency change ($\Delta SE_i^{t,t+1}$)", "technical change under VRS ($\Delta T_{BCC,i}^{t,t+1}$)" and "residual index of scale change under VRS ($\Delta S_i^{t,t+1}$)".

Countries whose banks experienced a decline in overall technical efficiency after the Asian financial crisis include: Indonesia, Thailand and Malaysia, suggesting the banking sector of these countries was adversely affected by the financial crisis, with a decline in the "pure efficiency change ($\Delta PE_i^{t,t+1}$)" being the common factor attributed to the decline in overall technical efficiency.

Finally, Panel Estimation made a number of discoveries. From 1993 to 2000, while the "pure efficiency change ($\Delta PE_i^{t,t+1}$)" rose in Indonesia, the corporate value of banks decremented significantly, reaching a 5% level. However, while the "scale efficiency change ($\Delta SE_i^{t,t+1}$)" rose, the value of Indonesian banks incremented (reaching a 10% level), suggesting a significant positive relationship between corporate value and "scale efficiency change ($\Delta SE_i^{t,t+1}$)." Before the Asian financial crisis (1993 to 1997), the "technical change under VRS ($\Delta T_{BCC}^{t,t+1}{}_{,i}$)" was the key factor bringing about an increase in the corporate value of banks in Taiwan, the "pure efficiency change ($\Delta PE_i^{t,t+1}$)" was the key factor bringing about the rise in corporate value of banks in Singapore, and the "scale efficiency change ($\Delta SE_i^{t,t+1}$)" and "residual index of scale change under VRS ($\Delta S_i^{t,t+1}$)" were the key factors prompting the rise in the corporate value of banks in Korea. After the Asian financial crisis (1998 to 2002), the "pure efficiency change ($\Delta PE_i^{t,t+1}$)" was the key factor bringing about a rise in corporate value of banks in the Philippines. There is a positive relationship between "pure efficiency change ($\Delta PE_i^{t,t+1}$)" and market returns. It also implies that improvements in the pure efficiency of banks accompany a rise in corporate value. The index "scale efficiency change ($\Delta SE_i^{t,t+1}$)" was also a key factor bringing about the growth in corporate value of Korean banks. These phenomena are identical to the situation that existed prior to the Asian financial crisis (1993 to 1997). Correlation analysis results found that "pure efficiency change ($\Delta PE_i^{t,t+1}$)", "scale efficiency change ($\Delta SE_i^{t,t+1}$)" and "technical change under VRS ($\Delta T_{BCC}^{t,t+1}{}_{,i}$)" were important factors influencing the corporate value of banks before the Asian financial crisis (1993 to 1997). After the Asian financial crisis (1998 - 2002), "scale efficiency change ($\Delta SE_i^{t,t+1}$)" and "pure efficiency change ($\Delta PE_i^{t,t+1}$)" were the important factors influencing the corporate value of banks, indicating that "scale efficiency change ($\Delta SE_i^{t,t+1}$)" and "pure efficiency change ($\Delta PE_i^{t,t+1}$)" played an important role in the market capitalization of banks.

The findings of this study offer reference value for banks in the formulation of future business administrative strategies. They are also a reminder for investors to pay attention to the operating efficiency of firms when they make investment decisions. These findings offer implications for investors in decision-making and considerable policy relevance. From the regulatory and supervisory perspective, the policy direction will be directed towards enhancing the resilience and efficiency of the financial institutions with the aim of intensifying the stability of the financial system.

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Appendix 1

MALMQUIST PRODUCTIVITY INDEX AND DECOMPOSITION OF NON-PARAMETRIC ESTIMATES

Definition of productivity index

The Malmquist productivity index was first introduced by Malmquist (1953) who proposed the construction of quantity indexes based on distance functions. Later on, Caves et al. (1982) further applied this notion as “the ratio of two distance functions pertaining to distinct time period.” Caves et al. (1982) surmise that the productivity level of a firm may be measured by the relationship between “inputs” and “outputs” variables. In the case of a technology with just one input and one output, a productivity index can be computed as the ratio thus:

$$\frac{y_i^t}{x_i^t}$$

Where y_i^t is the quantity of output produced by bank *i* at period *t* and x_i^t the quantity of input employed by bank *i* during at period *t.*

In the case of a multidimensional production technology, the quantities of inputs and outputs are expressed by vectors. The resulting productivity index can be defined as:

$$\frac{g^t(y_i^t)}{h^t(x_i^t)}$$

Where, $g^t(y_i^t)$ $u^t y_i^t$ is an output aggregation function with u^t being the weighting vector, and $h^t(x_i^t)$ $v^t x_i^t$ is an input aggregation function with v^t being the weighting vector.

The weighting vector above uses the prices of inputs and outputs for computation of weights. In addition, as Malmquist index uses primarily data on quantities to compute productivity index, the appropriate weights for inputs and outputs can be computed as a ratio of distance functions.

Using “distance function” to compute “relative productivity index”

Distance functions are derived by comparing one firm with another that acts as an optimal benchmark. Hence, the notion of “relative productivity index” (*RPI*) is created, which can be computed by dividing the absolute productivity index of the sample firm under study by that of the optimal benchmark firm. In other words, the *RPI* can be defined as:

$$RPI_i^t = \frac{g^t(y_i^t)/h^t(x_i^t)}{g^t(y_*^t)/h^t(x_*^t)} \qquad (1)$$

The symbol of * represents the benchmark firm that has attained the highest ratio of absolute productivity. Hence, the benchmark firm has relative productivity index of one, while other firms will have relative productivities of less than one. Gascón et al. (2002) employ distance function to compute *RPI* under the assumptions of constant returns to scale (that is, first degree homogeneity) and separability of inputs and outputs for the production technology, and thereby define “output distance function” as follows:

$$DC_i^t(x_i^t, y_i^t) = \min\left\{\theta : (x_i^t, \theta^{-1} y_i^t) \in T_{CCR}^t\right\} \qquad (2)$$

T_{CCR}^t represents the *CCR* technology, which satisfies the assumptions in Charnes et al. (1978) about “constant returns to scale (CRS)” and “free selection of inputs and outputs.” The distance function indicates the proportion of expandability of output vector under the premises of constant input vector, that is, the measure of “relative productivity.” Hence, the value of the distance function for a firm can be computed by solving the following linear equation:

$$DC_i^t(x_i^t, y_i^t) = \max \theta = \frac{u^t y_i^{t'}}{v^t x_i^{t'}} \qquad (3)$$

$$s.t. \frac{u^t y_j^{t'}}{v^t x_j^{t'}} \le 1, j \in J$$

$$u^t, v^t \ge 0$$

Where *J* represents the set of firms used to construct the empirical reference technology; these firms are assigned the symbol *j* to distinguish them from firm *i* under study.

The linear equation above finds the vector weights (μ^* ,υ^*) that maximize the relative productivity of firm *i,* where the objective function measures the distance between firm *i* and the benchmark firm in terms of productivity. Hence, the *RPI* derived is equal to distance function as shown in Equation (4):

$$RPI_i^t = DC_i^t(x_i^t, y_i^t) \qquad (4)$$

The Malmquist index proposed by Caves et al. (1982) measures the variation in the relative productivity of a firm between two time periods as referenced to the same benchmark firm. Thus, the Malmquist index at period t is as depicted in Equation (5), where the main difference between the distance functions in the numerator and the denominator are the activity vectors of firm *i* being evaluated, while the technology of the benchmark firm in both periods is constructed based on the data of period *t*.

$$M_{CCD}^{t} = \frac{DC_i^{t}(x_i^{t+1}, y_i^{t+1})}{DC_i^{t}(x_i^{t}, y_i^{t})} \quad (5)$$

Similarly the Malmquist index at period *t+1* can be measured as depicted in Equation (6), while the technology of benchmark firm in both periods is constructed based on the data of period *t+1.*

$$M_{CCD}^{t+1} = \frac{DC_i^{t+1}(x_i^{t+1}, y_i^{t+1})}{DC_i^{t+1}(x_i^{t}, y_i^{t})} \quad (6)$$

To avoid arbitrary choice of technology in period *t* or period *t+1* in the computation of Malmquist index that will result in data bias, Gascón et al. (2002) further calculates the geometric mean of the Malmquist indexes in period *t* and period *t+1* as illustrated in Equation (7):

$$M_{CCD}(x_i^{t+1}, y_i^{t+1}, x_i^{t}, y_i^{t}) = \left[\frac{DC_i^{t}(x_i^{t+1}, y_i^{t+1})}{DC_i^{t}(x_i^{t}, y_i^{t})} \frac{DC_i^{t+1}(x_i^{t+1}, y_i^{t+1})}{DC_i^{t+1}(x_i^{t}, y_i^{t})}\right]^{\frac{1}{2}} \quad (7)$$

Decomposition of Malmquist index

If $M_{CCD}(x_i^{t+1}, y_i^{t+1}, x_i^{t}, y_i^{t})$ 1, it implies that productivity growth might come from different factors. For example, it is possible that the sample firm improved its level of efficiency relative to the benchmark firm that is, the firm improved more than the benchmark firm. On the other hand, the productivity growth of sample firm might be attributed to its technological advancement. Färe et al. (1994) first propose that Malmquist index could be further decomposed into two factors of productivity variation, that is (1) the efficiency change of firm *i*, and (2) industry-wide technical change as shown in Equation (8):

$$M_{CCD}(x_i^{t+1}, y_i^{t+1}, x_i^{t}, y_i^{t}) = \frac{DC^{t+1}(x_i^{t+1}, y_i^{t+1})}{DC^{t}(x_i^{t}, y_i^{t})}\left[\frac{DC^{t}(x_i^{t+1}, y_i^{t+1})}{DC^{t+1}(x_i^{t+1}, y_i^{t+1})} \frac{DC^{t}(x_i^{t}, y_i^{t})}{DC^{t+1}(x_i^{t}, y_i^{t})}\right]^{1/2}$$

$$\equiv \Delta efficiency * [\Delta technical] = \Delta EF_i^{t,t+1} \, \Delta T_{CCR,i}^{t,t+1} \quad (8)$$

The first term in (8) represents the relative efficiency change of firm *i*, that is, the variation of firm *i* own distance function. The second term represents the productivity change (including firm *i* and other firms in the industry) that can be attributed to a movement in the CCR frontier between *t* and *t+1* as proposed by Charnes, et al. (1978). To extract more productivity variation factors, Simar and Wilson (1998) and Zofio and Lovell (1998) further decompose the aforementioned "efficiency change" and "technical change" into four indexes. That is, the "efficiency change index" is further decomposed into two indexes, one of which is pure technical efficiency which is computed based on the variable returns to scale technology, and the other is scale efficiency change. The decomposition process is as follows: Let

$$DV_i^{t}(x_i^{t}, y_i^{t}) = \min\left\{\theta : (x_i^{t}, \theta^{-1} y_i^{t}) \in T_{BCC}^{t}\right\} \quad (9)$$

Equation (9) depicts the output distance function, that is, T_{BCC}^{t} as defined by Banker, et al. (1984). The BCC technology relieves the CRS assumption of constant returns to scale technology (CRS) and adds only an assumption of convexity. That is, the BCC product set satisfies "variable returns to scale" (VRS). Gascón et al. (2002) compare the distance functions under CRS and VRS to derive a "residual scale efficiency index" (SE_i^{t}):

$$SE_i^{t}(x_i^{t}, y_i^{t}) = \frac{DC_i^{t}(x_i^{t}, y_i^{t})}{DV_i^{t}(x_i^{t}, y_i^{t})} \quad (10)$$

This is arranged into Eq. (11):

$$\Delta EF_i^{t,t+1} = \frac{DC_i^{t+1}(x_i^{t+1}, y_i^{t+1})}{DC_i^{t}(x_i^{t}, y_i^{t})}$$

$$\equiv \frac{DV_i^{t+1}(x_i^{t+1}, y_i^{t+1}) * SE_i^{t+1}(x_i^{t+1}, y_i^{t+1})}{DV_i^{t}(x_i^{t}, y_i^{t}) * SE_i^{t}(x_i^{t}, y_i^{t})}$$

$$\equiv \Delta PE_i^{t,t+1} * \Delta SE_i^{t,t+1} \quad (11)$$

It is learned from Equation (11) that the Malmquist index can be finally decomposed into three indexes: (1) pure efficiency change (relative to the VRS), i.e. $\Delta PE_i^{t,t+1}$; (2) scale efficiency change $\Delta SE_i^{t,t+1}$ (comparing the distance function under CRS with that under VRS); and (3) technical change $\Delta T_{CCR,i}^{t,t+1}$ (which reflects the movement of the CRS frontier).

According to the decomposition theory of Färe et al. (1994), the third term (technical change) $\Delta T_{CCR,i}^{t,t+1}$ in Equation (11) can be decomposed further into two components. Ray and Desli (1997) propose using VRS production set as reference technology to compute technical change. The difference between the Färe et al. (1994) and the Ray and Desli (1997) in the treatment of indexes of technical change lie in the residual measure of scale change of the technology. This term can reflect whether the projection of the firm on the VRS frontier is now closer or farther from the projection on the CRS frontier (i.e. the optimal scale). On such basis, Simar and Wilson (1998) and Zofío and Lovell (1998) further decompose the Malmquist index into four components as shown in Equation (12):

$$M_{CCD}(x_i^{t+1}, y_i^{t+1}, x_i^{t}, y_i^{t}) = \frac{DC_i^{t+1}(x_i^{t+1}, y_i^{t+1})}{DC_i^{t}(x_i^{t}, y_i^{t})} \left(\frac{DC_i^{t}(x_i^{t+1}, y_i^{t+1})}{DC_i^{t+1}(x_i^{t+1}, y_i^{t+1})} \frac{DC_i^{t}(x_i^{t}, y_i^{t})}{DC_i^{t+1}(x_i^{t}, y_i^{t})} \right)^{1/2}$$

$$\equiv \frac{DV_i^{t+1}(x_i^{t+1}, y_i^{t+1})}{DV_i^{t}(x_i^{t}, y_i^{t})} \frac{SE_i^{t+1}(x_i^{t+1}, y_i^{t+1})}{SE_i^{t}(x_i^{t}, y_i^{t})} \left(\frac{DV_i^{t}(x_i^{t+1}, y_i^{t+1})}{DV_i^{t+1}(x_i^{t+1}, y_i^{t+1})} \frac{DV_i^{t}(x_i^{t}, y_i^{t})}{DV_i^{t+1}(x_i^{t}, y_i^{t})} \right)^{1/2} * \left(\frac{SE_i^{t}(x_i^{t+1}, y_i^{t+1})}{SE_i^{t+1}(x_i^{t+1}, y_i^{t+1})} \frac{SE_i^{t}(x_i^{t}, y_i^{t})}{SE_i^{t+1}(x_i^{t}, y_i^{t})} \right)^{1/2}$$

$$\equiv \Delta PE_i^{t,t+1} * \Delta SE_i^{t,t+1} * \Delta T_{BCC,i}^{t,t+1} * \Delta S_i^{t,t+1} \quad (12)$$

Equation (12) depicts the further decomposition of the technical change component ($\Delta T_{CCR,i}^{t,t+1}$) in Equation (11) into: (1) an index measuring the technical change under VRS $\Delta T_{BCC,i}^{t,t+1}$; and (2) a residual index of scale change under VRS ($\Delta S_i^{t,t+1}$), where:

$$\Delta T_{CCR,i}^{t,t+1} = \Delta T_{BCC,i}^{t,t+1} * \Delta S_i^{t,t+1} \quad (13)$$