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A comprehensive analysis of the effects of risk measures on bank efficiency: Evidence from emerging Asian countries ☆

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ABSTRACT

This study investigates the role of risk in determining the cost efficiency of international banks in eight emerging Asian countries. Researchers of this paper consider three distinct risk aspects under a total of eight risk measures: credit risk, operational risk, and market risk. We apply a heteroscedastic stochastic frontier model to estimate bank cost efficiency in our analysis. Additionally, this study analyzes the marginal effects of all risk measures on the inefficiency effect in order to explore a more detailed relationship between risks and efficiency. The empirical results indicate that the risk measures represent significant effects on both the level and variability of bank efficiency. We also find that these effects vary across countries and over time.

1. Introduction

The efficiency of financial institutions has long been a focus of banking research. The findings have obvious implications for bank management who seek to improve operating performance and for policy makers who are concerned about bank competition, bank safety, and bank soundness.

The banking efficiency literature has been dominated by studies in the competitive banking markets of the US, Europe, or other developed countries. Berger and Humphrey (1997) excellently survey 130 efficiency studies of financial institutions, of which very few address the applications in Asian countries. The coincidence of banking and currency problems associated with the Asian financial crisis has drawn renewed attention to the development of the banking sector among Asian economies. People nowadays pay more and more attention to Asian countries especially those emerging markets[1] in the process of rapid growth and industrialization, and undoubtedly China and India are considered to be by far the two largest.

Yeh (1996) applies efficiency techniques to Taiwanese banks in the first study using data of an emerging Asian market. The limited amount of bank efficiency studies so far that have used banking data of emerging Asian markets includes Bhattacharyya et al. (1997) on India, Chang (1999), Chiu and Chen (2009) and Hsiao et al. (2010) on Taiwan, Okuda (2000) on the Philippines, Fu and Heffernan (2007) and Berger et al. (2009) on China, Banker et al. (2010) on South Korea, Laeven (1999) on Indonesia, Malaysia, the Philippines, South Korea and Thailand, Haw et al. (2010) on Indonesia, Malaysia, the Philippines, South Korea, Taiwan and Thailand, and Lozano-Vivas and Pasiouras (2010) on the emerging Asian markets except Taiwan.

The financial crisis that hit Asian countries has revealed substantial vulnerabilities in the financial sector. Banking crises have

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[1] The FTSE Group distinguishes between advanced and secondary emerging markets on the basis of their national income and the development of their market infrastructure and provides a list including 23 emerging markets, of which eight markets are in Asia. They are the markets of China, India, Indonesia, Malaysia, the Philippines, South Korea, Taiwan, and Thailand.

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become worldwide phenomena in recent years and it turns out that the key factors appear to be weak management and poor control of risks. Actually, risk is an essential ingredient in bank production. Banks specialize in risk assessment, risk monitoring, and risk diversification.

Traditional bank efficiency models have the disadvantage in that they do not take into account risk factors, which means those efficiency measures are not sufficient to assess a bank's the overall performance. The reason lies in that they assume all banks to be risk neutral, and they ignore risk-taking by banks. A particular case is when loan data are distorted by inadequately reported non-performing loans. An application of such distorted data to efficiency models might lead to incorrect conclusions (Laeven, 1999). Therefore, many studies attempt to obtain risk-adjusted efficiency measures.

Our paper takes into consideration risk factors and adopts Wang's (2002) heteroscedastic stochastic frontier model in the estimation, allowing us to specify both the mean and variance of the inefficiency turbulence and investigate the non-monotonic effects on efficiency. The empirical application is also quite different. We focus on the emerging Asian markets, which contain commercial banks publicly listed in eight countries: China, India, Indonesia, Malaysia, the Philippines, South Korea, Taiwan, and Thailand.

The remainder of the paper is organized as follows. Section 2 reviews the literature on risk and bank efficiency. Section 3 introduces the theoretical heteroscedastic stochastic frontier model and describes the data in details. Section 4 provides an empirical analysis and explains the relationship between risk and bank efficiency. Section 5 concludes our study.

2. Risk and bank efficiency: literature review

A risk-averse bank might choose to fund its loans with a higher ratio of financial capital-to-deposits than a risk-neutral bank. Since financial capital is typically more expensive than deposits, this might lead one to conclude that the risk-averse bank produces its output in an allocatively inefficient manner, when actually it is the risk-preferences that differ. In order to control for these differences in risk-preferences, Mester (1996) claims that the level of financial capital should be included in the cost function. Chang (1999) presents a non-parametric approach to incorporate three risk factors (non-performing loans, allowance for loan losses, and risky assets) into the measurement of technical efficiencies of the major financial intermediaries in rural Taiwan. Her test results support the idea that incorporating risk as an undesirable output has significant impacts on the ranking of efficiency performance.

Altunbas et al. (2000) investigate the impact of risk on bank efficiency for a sample of Japanese commercial banks between 1993 and 1996. They use loan loss provisions, financial capital to control risk. Their findings suggest that optimal bank size is considerably smaller when risk factors are taken into account, and the level of financial capital has the largest influence on the scale efficiency estimates. Iannotta et al. (2007) use the ratio of loan loss provision to total loans as a proxy for both asset quality and risk to compare the performance and risk of a sample of 181 large banks from 15 European countries over the 1999–2004 period. They present that public sector banks are on average less profitable and riskier than other banks, while mutual banks have better loan quality and lower asset risk than both private and public sector banks. Pasiouras (2008) uses DEA to investigate the efficiency of the Greek commercial banking industry over the period 2000–2004 and indicates that the inclusion of loan loss provisions as an input increases the efficiency scores.

It seems that most studies in the existing literature mainly use credit risk indicators, including non-performing loans and allowance for loan losses and risky assets, to explain bank efficiency scores, but do not consider other kinds of risks associated with bank efficiency. However, loaning funds to the demand side is no longer the main business of banks. They are exposed to various sources of risks, which may even be due to exogenous circumstances. In January 2001 the Basle Committee divides calculating bank risks into three major parts: credit risk, operational risk, and market risk. Credit risk is the risk of loss due to a debtor's non-payment of a loan or other lines of credit. Operational risk is the risk arising from the execution of a company's business functions. It is a very broad concept including fraud risks, legal risks, physical or environmental risks, etc. More specifically, Basel II defines operational risk as the risk of loss resulting from inadequate or failed internal processes, people and systems, or from external events. Market risk is the risk that the value of an investment will decrease due to moves in market factors including equity risk, interest rate risk, and currency risk. Thus, the non-performing ratio is no longer the only index to evaluate the risks of banks.

The literature also includes the estimates of bank efficiency using market or operational risk though they are somewhat incomplete. Armah and Park (1998) believe that agricultural banks face three major sources of risks. Default risk arises when borrowers cannot repay their loans and accrued interests. Liquidity risk derives from the uncertainty about banks' abilities to maintain enough funds to meet customers' loan demands. Interest rate risk is the hazard of banks refinancing their long-term loans at interest rates above the rates they receive.

Eisenbeis et al. (1999) find evidence that the stochastic frontier scores are more closely related to risk-taking behavior, managerial competence, and stock returns. They use the standard deviation of daily stock returns to measure the total systematic and non-systematic risks of the banking firm's common stocks. They use the standard deviation of residuals from the market model to measure the non-diversifiable idiosyncratic risk. They also use the ratio of loan charge-offs to loans outstanding in order to measure the banking firm's exposure to credit risk. González (2005) analyzes the impact of bank regulation on bank charter value and risk-taking. He measures credit risk with the ratio of non-performing loans to total bank loans and measures overall risk with the standard deviation of daily bank stock returns. The results indicate that regulatory restrictions increase banks' risk-taking incentives by reducing their charter value. Chiu and Chen (2009) consider not only credit risk, but also market and operational risk factors such as the foreign exchange rate, the interest rate, and the economic growth rate to analyze Taiwanese bank efficiency.

Only a few studies examine how ROA's (Return on Assets') volatility affects bank efficiency. For example, using data on US banks over the period 1990–1995, Berger and Mester (1997) find a negative relationship between cost efficiency and the standard deviation of ROA. A similar result is found for the standard deviation of ROE (Return on Equity). They interpret the results as bad managers are poor at both operations and risk management. However, more recent studies using international data find some results contradicting the earlier findings for the US Isik and Hassan (2002) show that the standard deviation of ROE is positively related to input efficiency in the Turkish banking industry. Havrylchyk (2006) investigates the determinants of bank efficiency using non-parametric DEA on a sample of Polish banks between 1997 and 2001. Her result shows that the volatility of ROA significantly affects bank efficiency positively. She then runs regressions with ROA as a dependent variable and the variance of ROA as an explanatory variable. A positive correlation between ROA and variance of ROA suggests that riskier banks are not only more efficient, but also more profitable on average.

The circumstance above is somehow difficult to understand. If there is a trade-off between risk and efficiency, then banks that are poor at operations might also be poor at risk management. Furthermore, inefficient banks tend to have higher risk in stock returns, which means that stocks of inefficient banks tend to underperform their more efficient counterparts.

Under the consideration of the above findings, we believe that generally speaking, banks face three major sources of risks: credit risk, operational risk, and market risk. In our paper we try to incorporate all sources of risks mentioned above. We use loan loss reserves over gross loans to account for credit risk, which arises when borrowers cannot repay their loans and accrued interests. We use exchange rate volatility, interest rate volatility, and changes in the exchange rate and interest rate to measure market risk when the value of an investment drops due to moves in various market factors. We use ROA's volatility, stock return volatility, and equity to asset ratio to reflect operational risk, which derives from a bank's essential business performance and also include dummy variables to capture the financial environmental risk of the Asian financial crisis in 1997–1998 and global financial crisis in 2008, respectively.

3. Methodology and data

3.1. Empirical method

There are two broadly empirical ways to measure bank efficiency: the parametric stochastic frontier approach (SFA) and the non-parametric data envelopment analysis (DEA). To measure the efficiency of banks in emerging Asian markets, we tend to employ parametric SFA. Possible reasons to prefer SFA over DEA are plentiful. First, DEA does not assume statistical noise, which means that the error term in the estimation is attributed to inefficiency. Thus, DEA accounts for the influence of factors such as regional price differences, luck, bad data, and extreme observations as "inefficiency". Second, measured DEA efficiency in small samples is sensitive to the difference between the number of firms and the sum of inputs and outputs used.

The stochastic frontier approach, independently proposed by Aigner et al. (1977) and Meeusen and van den Broeck (1977), modifies the traditional assumption of a deterministic production frontier. Both studies specify a composed error with two components: a one-sided error that measures the non-negative inefficiency effects and random factors not controlled by the decision-making unit (DMU).

Some studies extend SFA to investigate the determinants of inefficiency among DMUs and assume that inefficiency effects are a function of some DMU-specific factors (Battese and Coelli, 1995). Recent efforts in modeling heteroscedasticity in inefficiency effects (u_{it}) consider a more flexible specification in two ways: Kumbhakar et al. (1991) assume that the mode of u_{it} (i.e., μ_{it}) differs among DMUs. Caudill et al. (1995) assume μ_{it} to be constant, but allow the variance of pre-truncated distribution (σ_{it}^2) to be observation-specific.

Wang (2002) combines the feature of traditional models and those extended models above and allows both μ_{it} and σ_{it}^2 to be observation-specific. Suppose that total costs for the ith bank in year t are represented by TC_{it}, then Y_{it} and P_{it} are vectors of the output and the price of the input, respectively. The heteroscedastic stochastic frontier model specification for the cost function can be presented as below:

$$\begin{aligned}&\mathrm{TC}_{it} = f(Y_{it}, P_{it}) + v_{it} + u_{it}, \quad v_{it} \sim N(0, \sigma_v^2), \quad u_{it} \sim N^+(\mu_{it}, \sigma_{it}^2)\\&\mu_{it} = \delta_0 + Z_{it}\delta\\&\sigma_{it}^2 = \exp(\gamma_0 + Z_{it}\gamma),\end{aligned} \tag{1}$$

where v_{it} is the stochastic error term with i.i.d. normal distribution. This model assumes that u_{it} has a truncated normal distribution with an observation-specific mean (μ_{it}) and variance (σ_{it}^2) of its pre-truncated distribution. Moreover, the heteroscedastic stochastic frontier model also assumes μ_{it} and σ_{it}^2 are a function of some determinants (Z_{it}). Lai and Huang (2010) illustrate that this general setting in Wang's (2002) model is the best specification among eight well-known stochastic frontier models.

A special feature in Wang's (2002) model is that it allows the determinants (Z_{it}) to have non-monotonic effects on the inefficiency effect (u_{it}). The traditional SFA models implicitly assume that the determinants have strictly increasing or decreasing effects on the inefficiency effect. In Wang's model, Z_{it} can positively (negatively) affect the mean and variance of the inefficiency effect when values of Z_{it} are within a certain range, and then turn negative (positive) for values of Z_{it} outside the range. Such non-monotonic effects are measured by the marginal effects.

The non-monotonic efficiency effects on $E(u_{it})$ of the jth element of Z_{it} can be estimated as follows:

$$\begin{aligned}\frac{\partial E(u_{it})}{\partial z[j]} &= \delta[j]\left[1 - \Lambda\left[\frac{\phi(\Lambda)}{\Phi(\Lambda)}\right] - \left[\frac{\phi(\Lambda)}{\Phi(\Lambda)}\right]^2\right]\\&\quad + \gamma[j]\frac{\sigma_{it}}{2}\left[(1+\Lambda^2)\left[\frac{\phi(\Lambda)}{\Phi(\Lambda)}\right] + \Lambda\left[\frac{\phi(\Lambda)}{\Phi(\Lambda)}\right]^2\right],\end{aligned} \tag{2}$$

where ϕ and Φ are the probability and cumulative density functions of a standard normal distribution, respectively; $\Lambda = \mu_{it}/\sigma_{it}$; $z[j]$ is the jth element of Z_{it}; and $\delta[j]$ and $\gamma[j]$ are the corresponding coefficients in Eq. (1). Additionally, the marginal effect of Z_{it} on $V(u_{it})$ can be represented as:

$$\begin{aligned}\frac{\partial V(u_{it})}{\partial z[j]} &= \frac{\delta[j]}{\sigma_{it}}\left[\frac{\phi(\Lambda)}{\Phi(\Lambda)}\right](m_1^2 - m_2) + \gamma[j]\sigma_{it}^2\left\{1\frac{1}{2}\left[\frac{\phi(\Lambda)}{\Phi(\Lambda)}\right]\right.\\&\quad\left.\times\left(\Lambda + \Lambda^3 + (2+3\Lambda^2)\left[\frac{\phi(\Lambda)}{\Phi(\Lambda)}\right] + 2\Lambda\left[\frac{\phi(\Lambda)}{\Phi(\Lambda)}\right]^2\right)\right\},\end{aligned} \tag{3}$$

where m_1 and m_2 are the first two moments of u_{it} (see Wang, 2002).

3.2. Model specification and data description

Based on the intermediation approach, this paper specifies four outputs and two input prices. The output variables encompass total loans (*TL*), other earning assets (*OEA*), total deposits (*TD*), and liquid assets (*LA*). These four output variables are commonly adopted in the previous literature, such as Berger et al. (2009) and Bonin et al. (2005). It is noteworthy that the quality of loans (e.g., non-performing loans or problem loans) has received more emphasis in recent studies. Therefore, loan loss provisions are subtracted from total loans in order to ensure that this output entails comparable quality (Havrylchyk, 2006).

With respect to input prices, the price of labor, capital, and funds are the conventional input prices in previous research studies (Altunbas et al., 2001; Beccalli et al., 2006). However, data on personnel expenses are either missing or unavailable for some sample banks, especially for most Chinese banks. Considering the sample size and consistency among eight countries, we only regard the latter two variables as the input prices in this paper. Price of funds (*PF*) defined by the ratio of interest expenses to total deposits; Price of capital (*PC*) measured by the ratio of non-interest expenses to total fixed assets. The total costs (*TC*) of each sample bank consist of interest expenses and non-interest expenses.

This study estimates cost efficiency by specifying a commonly used translog function form for the cost function. Notice that *TC* and *PC* are scaled by *PF* in order to guarantee linear homogeneity in the input prices of the cost function. In other words, this scaling implies that the sum of the coefficients for *PC* and *PF* is equal to unity.

This study emphasizes the relationship between banks' cost efficiency and three distinct risk sets: credit risk, operational risk, and market risk. The first measure is the ratio of loan loss reserves over gross loans (*LLR*) used to measure output quality and how the manager invests in high risky assets. The second set contains three variables for accounting operational risk: ROA volatility, stock return volatility, and equity to asset ratio. Here, ROA volatility is an accounting-based volatility indicator calculated by a logged 5-year standard deviation of ROA (*ROA_V*). Stock return volatility is a market-based volatility indicator and is computed by the annualized standard deviation from the monthly log return (*Ret_V*). The equity to asset ratio (*ETA*) measures the equity position of a bank as a fraction to total assets. This ratio can be used as a proxy for whether a bank manager is risk-averse or risk-loving. With respect to market risk, this paper uses the annualized standard deviation from the daily exchange rate return (*Ex_V*), the standard deviation from the monthly interest rate (*Interest_V*), and the changes of exchange rate (*Ex change*) and interest rate (*Interest change*) from $t-1$ to t. The country effect is also considered and measured with country dummy variables (the omitted class is China).

This paper collects unbalanced panel data covering 1998–2008 from eight emerging Asian countries defined by MSCI Barra. The sample banks are constituted by listed and delisted commercial banks in each country, since this study examines the effect of stock return volatility. The financial data, including the balance sheets and income statements, are taken from Bankscope, a comprehensive data resource of international banking institutions. All nominal prices are transferred using each country's GDP deflator provided by the International Monetary Fund (IMF) with 2000 as the base year. Monthly stock price data of listed and delisted banks also come from Bankscope. The exchange rate data source is obtained from Taiwan Economic Journal (TEJ) database. We exclude banks that have less than 5 years of data because of the requirement for calculating ROA volatility. Therefore, the unbalanced dataset consists of 178 banks from eight emerging Asian countries with a total of 738 bank-year observations. Table 1 presents the summary statistics of the used variables in this study.

4. Results

4.1. The relationship between cost efficiency and risk measures

The estimations of the maximum likelihood function are carried using Stata 9.0 software and the estimation codes are kindly provided by Wang (2002). Table 2 provides the results of cost function estimations and the estimated effects of various risk measures on the inefficiency effect. The specifications of the cost function among each model are the same, while different risk determinants are used to cause different parameters estimation results. Models 1, 2, and 3 list three categories of risk: credit risk, market risk, and operational risk. Model 4 presents an integral estimation for all risk measures used in this paper. Country dummy and 2 year dummy variables (Asian financial crisis and the global financial crisis in 1998 and 2008, respectively) are treated as control variables for country effects and specific events in each model.

As shown in Table 2, the signs of all parameters in each model are almost identical, indicating a consistent and reasonable result.

Table 1
Statistics of variables used in the cost function.

	Mean	SD	Min.	Max.
Total cost (in billion US $)	0.971	1.770	0.003	20.897
Output quantities (in billion US $)				
Total loans	13.457	30.261	0.016	436.789
Other earning assets	7.459	24.738	0.007	445.614
Deposits	17.521	45.976	0.002	801.807
Liquid assets	5.932	14.530	0.005	244.974
Input prices				
Price of capital	2.824	11.318	0.065	279.226
Price of funds	0.212	2.115	0.009	41.822

Note: All nominal monetary variables are transferred to the 2000 price level.

Therefore, we take model 4 as an example to illustrate. Most of the coefficients of outputs are significantly positive. Although the input prices show a significantly negative effect on total costs, the coefficient of the quadratic term for input prices is positive and significant at 1% level. In addition, the input prices represent a positive relationship with total costs if ln(PC/PF) is higher than 1.20. Hence, these results mean that the higher the price of each inputs are and the more output that is produced, the higher the total costs are. With respect to the time effect, all the results reveal that the total costs in bank operation are increasing year by year, while this effect of rising costs declines gradually.

The relationship between banks' cost efficiency and risk is the main purpose of this paper. Therefore, the following focuses on how the risk measures affect the level and variability of the inefficiency effect. Model 1 of Table 2 only regards credit risk as the determinant of bank efficiency. It is found that the loan loss reserves ratio has a positive effect on the mean and variance of the inefficiency effect, indicating that a bank with a higher loan loss reserves ratio will have a lower and more varied cost efficiency. A higher loan loss reserves ratio implies that the bank may confront a larger possibility that its loans will become non-performing. Under this operation uncertainty, it is reasonable that a higher loan loss reserves ratio pushes banks' cost efficiency down and increases the fluctuation of cost efficiency.

Model 2 of Table 2 illustrates the effects of market risk on bank efficiency. The result shows that the exchange rate volatility of each country has a significantly negative effect on the inefficiency effect, meaning that banks operating in a high exchange rate volatility environment are more efficient than those operating in a low exchange rate volatility. The exchange rate change positively affects bank efficiency. Since a positive exchange rate change indicates local currency devaluation, this result reveals that banks' cost efficiency falls under the local currency devaluation. Moreover, an increasing exchange rate may stabilize banks' efficiency, indicating local currency devaluation will result in a sustained low efficiency.

Model 3 of Table 2 shows the relationship between operational risk factors and bank cost efficiency. It is found that the effect of ROA volatility on the mean of the inefficiency effect is positive and significant at the 10% level, meaning that a bank with higher ROA volatility is more inefficient than other banks. This result is in line with the work of Berger and Mester (1997), indicating that poor managers may be unfavorable to both cost and risk management. Furthermore, ROA volatility shows a significantly positive effect on the variance of the inefficiency effect. It is a reasonable good result that banks with high ROA volatility might increase their operation uncertainty.[2] Stock return volatility reveals a negative effect on the variance of the inefficiency effect, implying that banks with higher return volatility have steadier bank performance. Regarding the effect of the equity to asset ratio, the result shows that a lower ratio benefits bank efficiency, meaning that bank managers choose a higher debt ratio appropriate for operating efficiently.

Model 4 of Table 2 estimates the cost function and the effects of all risk variables on the inefficiency effect simultaneously. The result is almost identical with the conclusions of the previous three models except for two variables, i.e. interest rate volatility and interest rate change. Model 4 shows that a rising interest rate will increase the level of bank inefficiency, indicating that an increasing bank operation cost (especially the funding cost) might erode bank performance (revenue or profit). Moreover, the variability of the inefficiency effect grows if the interest rate volatility becomes more violent. A partial explanation is the fact that interest rate policy is essentially important for the banking industry since the

[2] This paper also applies ROE rather than ROA as an explanatory variable in Models 3 and 4. The results are quite consistent whether ROE or ROA is used. Hence, we do not present those results when ROE is used as explanatory variable.

Table 2
Estimation results for the cost frontier and the determinants of inefficiency.

Dependent variable ln(TC/PF)	Model (1)	Model (2)	Model (3)	Model (4)
β_0	−0.138	0.121	−0.156	−0.065
ln(PC/PF)	−0.068***	−0.061*	−0.089	−0.094***
ln(TL)	0.078	0.027	−0.195	0.137***
ln(OEA)	0.012	0.001	−0.091	0.129**
ln(TD)	0.898***	0.893***	1.220***	0.807***
ln(LA)	−0.008	0.054	0.077	−0.094**
$\ln(PC/PF)^2$	0.032***	0.025***	0.026**	0.039***
$\ln(TL)^2$	0.035	0.078	−0.001	0.019
$\ln(OEA)^2$	−0.035	−0.004	0.023	−0.013
$\ln(TD)^2$	0.026	−0.005	−0.078	−0.038
$\ln(LA)^2$	−0.002	−0.023	−0.003	0.024
ln(PC/PF) × ln(TL)	0.034***	0.014	−0.019	0.016***
ln(PC/PF) × ln(OEA)	−0.027*	0.003	−0.007	−0.032**
ln(PC/PF) × ln(TD)	−0.011	0.001	0.051	0.012***
ln(PC/PF) × ln(LA)	0.008	−0.001	−0.010	0.005
ln(TL) × ln(OEA)	−0.040**	−0.110**	−0.102	−0.058**
ln(TL) × ln(TD)	−0.069*	−0.049	0.022	−0.037
ln(TL) × ln(LA)	0.042***	0.078**	0.110*	0.040**
ln(OEA) × ln(TD)	0.094	0.130	0.120	0.116***
ln(OEA) × ln(LA)	−0.027	−0.009	−0.024	−0.063**
ln(TD) × ln(LA)	−0.016	−0.064	−0.098	0.004
Year	0.154***	0.090***	0.117***	0.155***
Year^2	−0.023***	−0.009***	−0.010***	−0.022***
ln(PC/PF) × year	0.005**	−0.004	−0.004	0.005**
ln(TL) × year	0.013***	0.012*	0.018*	0.015***
ln(OEA) × year	0.005	−0.006	−0.002	−0.001
ln(TD) × year	−0.013***	−0.010	−0.021	−0.015***
ln(LA) × year	−0.003	0.002	0.002	0.001
Number of obs.	738	738	738	738
Log *L*	487.788	414.589	432.096	535.252
Effects on μ_{it}				
δ_0	−0.273***	−1.651***	−1.796	−0.712***
LLR	6.580***			6.448***
ROA_V			0.022*	0.013**
Ret_V			−0.036	−0.017
ETA			0.010**	0.006*
Ex_V		−0.061*		−0.051***
Interest_V		0.016		−0.173
Ex change		0.437***		0.101*
Interest change		0.005		0.016***
ROA	0.010	0.009	−0.001	−0.003
Total assets	0.058***	0.078***	0.118***	0.064***
India	−0.125***	−2.426	−4.195**	−0.088***
Indonesia	0.038	0.912**	0.878	0.104***
Korea	0.089**	0.230	−0.271	0.167***
Malaysia	−0.150**	−0.159	−5.242***	−0.207***
Philippines	0.311***	1.127***	1.107	0.351***
Taiwan	0.203***	0.088	0.263	0.201***
Thailand	0.252***	0.973**	0.862	0.296***
Year 1998	0.128***	0.069	0.047	0.186***
Year 2008	0.027	0.041	0.120***	0.082***
Effects on σ^2_{it}				
γ_0	−1.067	−0.534	1.419	−1.617
LLR	14.441***			15.449**
ROA_V			0.571***	0.195***
Ret_V			−0.363**	−0.443**
ETA			0.037	0.036
Ex_V		−0.243		0.103
Interest_V		5.443		5.262**
Ex change		−2.546*		−0.484
Interest change		0.035		0.001
ROA	0.058	−0.391***	−0.287***	0.001
Total assets	−0.341***	−0.392***	−0.425**	−0.343***
India	−0.345	0.861	0.345	−0.121
Indonesia	−0.374	−1.915***	−3.369	−0.908*
Korea	−1.037***	0.220	−0.238	−1.323***
Malaysia	0.947	−0.439	0.952	0.351
Philippines	−0.897**	−1.716***	−2.803	−1.476***
Taiwan	0.580*	1.367	0.145	0.375
Thailand	0.813**	−4.460	−2.494	0.144
Year 1998	−2.122***	−1.036*	−0.817	−2.982***
Year 2008	−0.036	−0.106	−0.187	−0.454
σ_v	24.676***	4.911***	4.925***	26.833***

This paper specifies four outputs and two input prices. The output variables encompass total loans (TL), other earning assets (OEA), total deposits (TD), and liquid assets (LA). Two inputs are price of funds (PF) and price of capital (PC). The total costs (TC) of each sample bank consist of interest expenses and non-interest expenses. Models (1)–(3) reveal the effect of a separate risk category on the inefficiency term, i.e. credit risk, market risk, and operation risk in models (1), (2), (3), respectively. The determinants are LLR, the ratio of loan loss reserves over gross loans; ROA volatility, the 5-year standard deviation of ROA; Return volatility, the annualized standard deviation from the monthly log return; ETA ratio, the equity to asset ratio; Ex volatility, the annualized standard deviation from the daily exchange rate return; Interest volatility, the monthly standard deviation of the interest rate; Ex change, the difference between the exchange rate of t and $t-1$; Interest change, the difference between the interest rate of t and $t-1$. ROA, total assets, and country dummies are the control variables.

* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.

interest rate reflects the hazards of banks paying their interest expense or refinancing long-term loans. When a country's interest rate policy varies frequently, banks' operation uncertainty will increase and result in inputs be used inefficiently to produce outputs.

With respect to other control variables in Model 4 of Table 2, large banks seem to be less efficient than small banks. It is surprising that a bank's ROA has no effect on its efficiency. One possible reason is that risk measures could sketch bank efficiency more exactly than ROA. Another reason is that ROA may be endogenous and it needs a further econometric test to purify the relationship with cost efficiency (Lensink et al., 2008). Considering the country effect, it is in line with the expectation that South Korea, Indonesia, the Philippines, and Thailand present lower cost efficiency than China, because these four countries suffered severely from the 1997 Asian financial crisis. However, it is surprising that Malaysia shows higher cost efficiency than China, which might be due to the problem of insufficient samples, i.e. only five listed or delisted Malaysian banks collected in this paper. Furthermore, the signs of the event dummies (financial crises in 1998 and 2008) are also consistent with the expectation that an extensive financial crisis causes the efficiency of the bank industry to plunge worldwide.

In fact there has a potential endogeneity problem. To test this problem, this paper adopts a Durbin–Wu–Hausman test (see Davidson and MacKinnon, 1993). We treat LLR, ROA volatility, stock return volatility, and ETA ratio as endogenous but take market risk measures to be exogenous. Since identification requires at least four instrumental variables, we select total equity, liquid ratio, real GDP growth rate of each country, and stock market volatility of each country. These four variables are not weak instruments and do not correlate with total cost (an F-test statistic of joint significance is 0.78, with a p-value of 0.54). The result of Durbin–Wu–Hausman test (F-test statistic is 3.78, with a p-value of 0.44), then, does not indicate that endogeneity problem is a concern in this study. It is noteworthy that this result does not imply that risk measures are exogenous, only that no statistically significant problem arises from their endogeneity.[3]

4.2. The non-linear effect of risk measures

The non-monotonic effect of risk measures on the inefficiency effect is also emphasized in this research. The stochastic cost

[3] The authors thank an anonymous referee for constructive comments that motivated us to undertake the endogeneity analysis.

frontier estimation in Table 2 only shows the overall effects of risk measures on the level and variability of the inefficiency effect. This will capture more management insights if one considers the non-monotonic effects. According to Eqs. (2) and (3), we can calculate the marginal effects on the mean and variance of the inefficiency effect. We sort and classify the samples into five groups by each criteria variable. We then compare the average cost efficiency and the marginal effects on $E(u_{it})$ and $V(u_{it})$ across the groups (the lowest, middle, and highest groups). Hence, Table 3 lists the calculation results.

With respect to the non-monotonic effects on bank efficiency, Table 3 does not represent non-monotonic effects, but rather non-linear effects of some risk factors on the mean and variance of the inefficiency effect. The LLR and ROA volatility show similar patterns of a marginal effect on $E(u_{it})$ and $V(u_{it})$, indicating that the negative effects of LLR and ROA volatility on bank efficiency increase if the levels of these risk factors rise. Furthermore, the banks' cost efficiency becomes more variable if the levels of LLR and ROA volatility increase. Other risk measures, such as stock return volatility, ETA ratio, and exchange rate volatility, also present a non-linear effect on the variance of the inefficiency effect. Interest rate volatility and exchange rate volatility have a non-linear effect on $E(u_{it})$ and $V(u_{it})$, although the signs of these variables are quite contrastive.

This paper further analyzes the time trends of cost efficiency and average marginal effects on $E(u_{it})$ and $V(u_{it})$ over the sample period. We select several risk variables only if their overall effect is significant according to Table 2 and then compare the average marginal effects over 1998–2008. The calculation results are shown in Table 4.

Table 4 illustrates that the average cost efficiency of emerging Asian banks has gradually improved from 1998 (52.7%) to 2006 (71.9%), while a newly global financial storm sharply affects emerging Asian banks' efficiency in 2007 and 2008. With respect to the marginal effects, it is found that these effects of risk measures are not consistent over time. For instance, the marginal effect of LLR on $E(u_{it})$ is a U shape-like pattern. The marginal effect maintains a high level for pre-2001 and presents a downturn in 2001–2006. This effect then increases again after 2006, indicating that the negative effect on cost efficiency becomes serious. However, the marginal effects of ROA volatility and the ETA ratio on $E(u_{it})$ show inverse U shape-like patterns, which might mean that these effects weaken over the sample period though they still significantly and negatively affect cost efficiency.

Table 3
Cost efficiency and marginal effects by various sorted criteria.

Quintile	Mean of variables	Avg. cost efficiency	Marginal effect on $E(u_{it})$	Marginal effect on $V(u_{it})$
By LLR				
1st	0.0028	0.7428	5.6254***	0.3501***
3rd	0.0102	0.6539	6.1251***	0.4111***
5th	0.0340	0.6215	6.0803***	1.5084***
By ROA_V				
1st	−2.2615	0.6941	0.0138***	0.0021***
3rd	−0.7889	0.6996	0.0152***	0.0036***
5th	1.0849	0.6178	0.0191***	0.0173**
By Ret_V				
1st	0.0521	0.6490	−0.0263***	−0.0125***
3rd	0.1086	0.6624	−0.0232***	−0.0121**
5th	0.2059	0.7001	−0.0238***	−0.0099***
By ETA				
1st	3.7721	0.6575	0.0062***	0.0020*
3rd	6.8629	0.7067	0.0058***	0.0008***
5th	14.3520	0.6773	0.0063***	0.0017***
By Ex_V				
1st	0.0012	0.6911	−0.0434***	0.0008***
3rd	0.0033	0.6100	−0.0442***	0.0029***
5th	0.0079	0.6725	−0.0420***	0.0041*
By Interest_V				
1st	0.0053	0.7423	−0.0123	0.0690***
3rd	0.0258	0.6764	−0.0091	0.2611*
5th	0.1069	0.5851	−0.0638***	0.1697***
By Ex change				
1st	−0.1079	0.6965	0.0731***	−0.0089***
3rd	−0.0139	0.6412	0.0782***	−0.0144***
5th	0.1049	0.6742	0.0761***	−0.0246*
By interest change				
1st	−2.9542	0.6815	0.0131***	0.0004***
3rd	−0.2414	0.6785	0.0138***	0.0004***
5th	2.1193	0.7161	0.0138***	0.0003***

We sort and classify the samples into five groups by each criteria variable. We then compare the average cost efficiency, marginal effects on $E(u_{it})$ and $V(u_{it})$ across the groups (the lowest, middle, and highest groups). The listed variables are the same as the definitions of Table 2.
* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.

Table 4
Cost efficiency and the average marginal effects on $E(u_{it})$ and $V(u_{it})$ over the 1998–2008 period.

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Avg. CE	0.527	0.577	0.611	0.668	0.672	0.679	0.657	0.693	0.719	0.694	0.636
Avg. marginal effect on $E(u_{it})$											
LLR	6.448***	5.767***	6.745***	6.053***	5.970***	5.881***	5.839***	5.966***	5.827***	5.893***	6.346***
ROA_V $\times 10^{-2}$	1.264***	1.449***	2.291***	1.580***	1.687***	1.573***	1.479***	1.526***	1.512***	1.469***	1.313***
ETA $\times 10^{-3}$	5.950***	5.733***	7.477***	6.094***	6.177***	5.969***	5.821***	5.966***	5.855***	5.843***	5.945***
Ex_V $\times 10^{-2}$	−5.116***	−4.140***	−4.026***	−4.263***	−4.030***	−4.091***	−4.175***	−4.245***	−4.116***	−4.246***	−4.940***
Ex change $\times 10^{-1}$	1.013***	0.766***	0.632***	0.777***	0.710***	0.739***	0.770***	0.780***	0.752***	0.788***	0.967***
Interest change $\times 10^{-2}$	1.581***	1.343***	1.439***	1.396***	1.348***	1.348***	1.356***	1.383***	1.345***	1.374***	1.540***
Avg. marginal effect on $V(u_{it})$											
LLR	0.024***	0.464***	3.502*	0.589***	0.852***	0.535***	0.388***	0.440***	0.432***	0.414***	0.223***
ROA_V $\times 10^{-3}$	0.030***	0.496***	4.060*	0.584***	0.873***	0.509***	0.356***	0.409***	0.405***	0.395***	0.246***
Ret_V $\times 10^{-2}$	−0.069***	−1.115***	−9.185*	−1.302***	−1.953***	−1.131***	−0.787***	−0.906***	−0.898***	−0.876***	−0.554***
Interest_V	0.008***	0.127***	1.070	0.146***	0.221***	0.125***	0.086***	0.099***	0.099***	0.097***	0.064***

According to the estimation result of Table 2, the listed variables are selected only if their effects are significant. LLR is the ratio of loans loss reserves to gross loans; ROA_V is the volatility of ROA; Ret_V is the volatility of stock returns; ETA ratio is the equity to asset ratio; Ex_V and Interest_V are the volatility of exchange rate and interest rate, respectively; Exchange and Interest change are the changes of exchange rate and interest rate from $t-1$ to t, respectively.
* Significant at the 10% level.
*** Significant at the 1% level.

4.3. Further examination of cost efficiency across countries

Section 4.1 only uses country dummies as control variables and compares the average cost efficiency among other emerging Asian countries relative to China. In this sub-section, we further compare the trend pattern of each country's cost efficiency and examine whether the marginal effects of risk measures differ across countries. Fig. 1 delineates the average cost efficiency of each country over the 1998–2008 period. Except for Indonesia and Taiwan, there is an upward trend for most emerging Asian countries, indicating that these countries have gradually reformed their bank industry since the Asian financial crisis in 1997–1998. China and India, the two countries of BRICs, present higher cost efficiency and have improved their efficiency consistently. With respect to Taiwanese banks, Taiwan's banking industry has experienced a worsening asset quality problem, overbanking problem, and a credit card and cash card crisis since the impact of the Asian financial crisis in 1997–1998. After two financial system reforms in 2004, Taiwanese banks' cost efficiency has slowly improved year by year. The cost efficiency of Indonesia is the most volatile among the eight countries, which may result from the highest interest rate change/volatility and exchange rate change there.

This paper also compares the marginal effects on $E(u_{it})$ among some sorted criteria in each country. Similar to Table 3, we sort

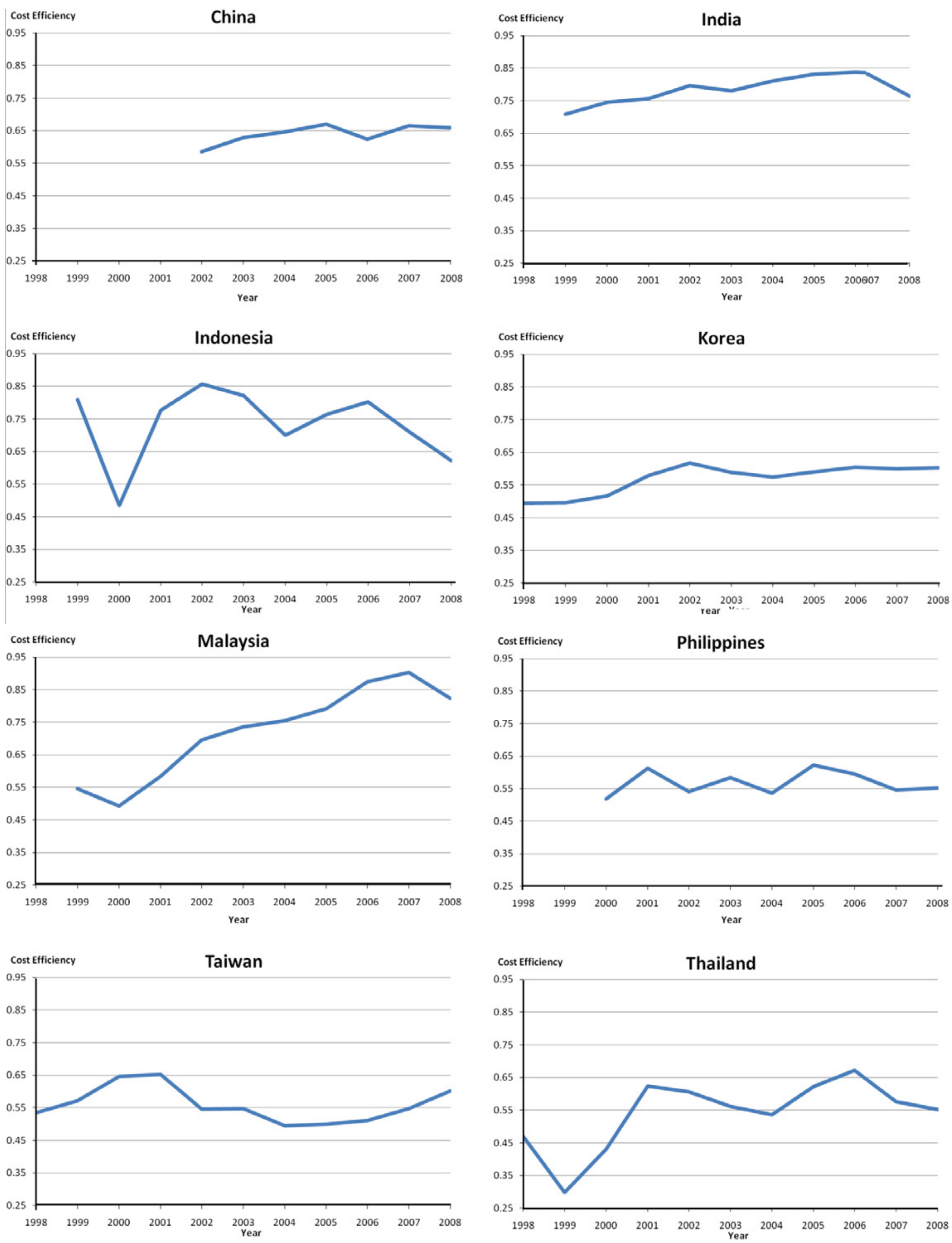

Fig. 1. Cost efficiency for emerging Asian countries over the 1998–2008 period.

Table 5
Comparing the marginal effects on $E(u_{it})$ among sorted groups in emerging Asian countries.

Marginal effect on $E(u_{it})$	China	India	Indonesia	South Korea	Malaysia	Philippines	Taiwan	Thailand
LLR								
Low	6.422***	5.158***	5.088***	6.447***	5.595***	6.416***	6.396***	6.382***
Middle	6.431***	5.409***	5.835***	6.445***	5.335***	6.395***	6.410***	6.369***
High	6.443***	5.509***	5.573***	6.445***	5.636***	6.417***	6.446***	6.736***
ROA_V $\times 10^{-2}$								
Low	1.266***	1.399***	1.675***	1.264***	1.636***	1.302***	1.301***	1.441***
Middle	1.264***	1.582***	1.533***	1.266***	1.734***	1.407***	1.372***	1.832***
High	1.303***	1.721***	2.075***	1.276***	1.755***	1.401***	1.390***	2.604***
Ret_V $\times 10^{-2}$								
Low	−1.775***	−2.650***	−3.369***	−1.692***	−3.196***	−2.177***	−2.030***	−2.693***
Middle	−1.708***	−2.727***	−3.620***	−1.712***	−2.810***	−1.885***	−1.840***	−3.168***
High	−1.685***	−2.631***	−2.346***	−1.685***	−2.940***	−1.784***	−1.869***	−4.275***
ETA $\times 10^{-3}$								
Low	5.950***	5.621***	6.409***	5.950***	5.633***	5.965***	6.061***	6.352***
Middle	5.951***	5.608***	5.760***	5.965***	6.013***	6.070***	6.050***	6.201***
High	5.971***	5.615***	5.704***	5.951***	6.065***	6.150***	6.027***	8.088***
Ex_V $\times 10^{-2}$								
Low	−5.115***	−3.510***	−3.380***	−5.110***	−4.468***	−5.058***	−4.950***	−4.000***
Middle	−5.029***	−3.496***	−3.714***	−5.100***	−3.336***	−4.703***	−4.929***	−4.102***
High	−5.095***	−3.625***	−3.190***	−5.115***	−2.851***	−5.035***	−4.999***	−4.543***
Interest_V								
Low	−1.727***	0.631***	2.137*	−1.689***	−0.174	−1.618***	−1.450***	1.320*
Middle	−1.576***	0.197	0.693**	−1.717***	1.948***	−1.597***	−1.371***	−0.243*
High	−1.692***	0.218	−0.183	−1.728***	0.310	−0.738*	−1.342***	0.795*
Ex change								
Low	0.099***	0.057***	0.044***	0.101***	0.035***	0.099***	0.097***	0.071***
Middle	0.100***	0.066***	0.067***	0.101***	0.077***	0.090***	0.096***	0.066***
High	0.101***	0.061***	0.057***	0.101***	0.065***	0.098***	0.096***	0.078***
Interest change								
Low	1.576***	1.186***	1.017***	1.580***	1.283***	1.509***	1.552***	1.401***
Middle	1.580***	1.180***	1.222***	1.577***	1.247***	1.555***	1.553***	1.465***
High	1.562***	1.228***	1.347***	1.580***	1.123***	1.575***	1.548***	1.451***

* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.

and classify the samples in each country into three groups (low, middle, and high) by each criterion. We then compare the marginal effect on $E(u_{it})$ across groups and countries. Table 5 gives the calculation results as below.

There are some interesting findings in Table 5: First, regarding the marginal effect of LLR, a distinct effect is found between China and India, which are the two highly efficient countries in this study. The average LLR is almost the same in the Chinese and Indian banking industries, while the negative effect on Chinese banks' cost efficiency is quite larger than India. Second, some risk variables present an inefficient linear effect for some emerging Asian countries, but have a non-linear effect for other countries. For example, the effect of ROA volatility on Chinese or Korean banks' efficiency is nearly the same across the three groups, indicating a positively linear effect. However, the effect of ROA volatility on banks in Thailand is likely non-linear effect, i.e. the higher the ROA volatility a bank has, the larger the positive effect will be. The same pattern is also presented when considering the equity to asset ratio. Third, interest rate volatility does not show a significant effect on the inefficiency effect in Table 2, while this paper finds a diverse conclusion across countries in Table 5. A higher interest rate volatility for banks in China, South Korea, the Philippines, and Taiwan will benefit their cost efficiency, whereas there is an opposite conclusion if the banks operate in India.

It is notable that the effect of interest rate volatility on the banks of Indonesia, Malaysia, and Thailand reveals a non-monotonic pattern, especially for Thai banks (i.e. a positive inefficiency effect is present in the lowest and highest groups, but turns to a negative effect in the middle group). According to this table, we suggest that the bank manager can find out what is the most important factor in each different country. Moreover, we find an optimal level of interest rate volatility for making decisions, such as it is improper to keep a too low or too high volatility in Thailand.

5. Conclusions

This study explores the role of risk in determining the cost efficiency of international banks in emerging Asian markets. We consider three distinct risk aspects, including credit risk, operational risk, and market risk in this paper. Using a heteroscedastic and non-monotonic stochastic frontier approach, we find that each risk measure presents a dissimilar effect on banks' efficiency. LLR and ROA volatility show similar effect patterns on the mean and variance of the inefficiency effect (i.e., $E(u_{it})$ and $V(u_{it})$, respectively). Stock return volatility and interest rate volatility only affect the variability of bank efficiency. However, the other four measures (equity to asset ratio, exchange rate volatility, change of interest rate, and change of exchange rate) just influence the level of cost efficiency. The marginal effects in this paper reveal more detailed facts about how these risk measures influence both the level and variability of the inefficiency effect across countries and over time.

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