Determinants of efficiency in the malaysian banking sector: Does bank origins matter?

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Abstract

The paper follows Simar and Wilson's (2007) two-stage procedure to analyze the efficiency of the Malaysian banking sector. In the first stage, we employ the bootstrap Data Envelopment Analysis (DEA) method to compute the efficiency of individual banks during the period 1999–2008. We then use bootstrap regression to examine the impact of origins on bank efficiency, while controlling for the potential influence of contextual variables. The DEA results indicate that the Malaysian banking sector has exhibited increase in efficiency over the sample period. We find that banks from the Asian countries to be relatively more efficient compared to foreign banks from other regions and their domestic bank peers. In essence, the empirical evidence rejects the *home field advantage* hypothesis, but lends support to the "limited form" of the *global advantage* and the *liability of unfamiliarness* hypotheses.

1. Introduction

The importance of the banking sector is premised on the ground that banks are the main channels of savings and allocations of credit in an economy (Levine 1997; Dell' Ariccia and Marquez 2004). The banking sector provides important financial intermediation function by converting deposits into productive investments (King and

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Levine 1993a, 1993b). Unlike in other developed nations where financial markets and the banking sector works in unison to channel funds, in developing countries, financial markets are undersized and sometimes completely absent (Arun and Turner 2004). It falls on the banking sector to bridge the gap between savers and borrowers and to perform all tasks associated with the profitable and secure channeling of funds.

As in other developing economies, the banking system plays an important financial intermediary role in the Malaysian economy (Sufian, 2010b). The banking sector controls most of the financial flows and accounts for more than 70% of the financial system's total assets. Therefore, it is reasonable to expect that an efficient and profitable banking sector may help ensure an effective financial system which is conducive to economic growth and development. In this vein, Levine (1998), points out that the efficiency of financial intermediation affects a country's economic growth and at the same time, bank (financial intermediation) insolvencies could result in systemic crises and consequently negative implications on the economy. Consequently, knowledge of the underlying factors that influence the performance of the banking sector is essential for managers of the banks, the central bank, bankers association, and other financial authorities to help them formulate policies to improve the performance of the banking sector.

The purpose of the present study is to employ the DEA method to examine the efficiency of the Malaysian banking sector. The present paper contributes to the present literature in several important ways. First, the paper seeks to examine whether productive efficiency is significantly associated with the origins of the foreign banks after controlling for other internal (bank specific characteristics) and external (macroeconomic and industry specific) factors. Second, unlike the earlier studies focusing on the Malaysian banking sector (e.g., Sufian, 2010b; Matthews and Ismail, 2006; Katib and Matthews, 2000) the present study adopts the more recent DEA bootstrap method proposed by Simar and Wilson (1998, 1999, 2000). Finally, we employ the central tendency and parametric method based on bootstrap regression to investigate the potential impacts of contextual variables on the efficiency of the Malaysian banking sector.

This paper is set out as follows: In the next section we provide a brief overview of the Malaysian banking sector. We provide a brief review of the main literature in Section 3. In Section 4 we discuss the data and outline the approaches to the measurement of efficiency change. In Section 5, we present the bias-corrected DEA results and the bootstrap regression analysis results. Section 6 concludes the paper and offers avenues for future research.

2. Brief overview of the Malaysian banking sector

The Malaysian banking system can broadly be divided into the banking sector and non-bank financial intermediaries. These two groups differ from each other with respect to their activities. Out sizing non-bank intermediaries significantly, the banking sector accounts for approximately 70% of the banking system's total assets. Commercial banks are the main players in the banking sector and are the largest and most significant providers of funds. As at end–2008, it is clear from Table 1 that the commercial banking sector dominates the Malaysian financial system's assets and liabilities, with total assets and liabilities amounting to RM1600.5 billion ($462.6 billion). There were nine domestically incorporated and 13 locally incorporated foreign commercial banks in Malaysia as at end–2008.

Legally, Malaysian commercial banks enjoy the widest scope of permissible activities and are able to engage in a full range of banking services. Traditionally, Malaysian commercial banks main functions include retail-banking services, trade financing facilities, treasury services, cross border payment services, and custody services. Apart from the more traditional activities, Malaysian commercial banks are also allowed to engage in foreign exchange activities i.e., to buy, sell, and lend foreign currencies and are the only financial institutions allowed to provide current account facilities.

Despite controlling over 90% of the banking market in 1957, the foreign commercial banks' market share declined markedly after the country's Independence in 1957 to only 15.3% of the banking system's assets in 1997. The progressive decline of the foreign banks' market share was the result of government policy to encourage the development of the domestic banking sector. Foreign commercial banks have been prohibited to open new branches since 1971 and the last foreign bank allowed entry into the market was Bank of Nova Scotia in 1973. All foreign banks granted licenses after 1971 have had to remain one branch banks.

Banking regulations in place since 1994 require all existing foreign branch banks to be incorporated locally. Furthermore, all non-resident controlled companies are required to source a minimum of 50% of their domestic credit needs from a Malaysian owned bank. For regulatory purposes, any off-premises automated teller machine

Table 1
Assets of the financial system– 1990 – 2008.

Year	Commercial banks		Finance companies		Merchant banks	
	RM million	US$ million	RM million	US$ million	RM million	US$ million
1990	129,284.9	47,883.3	39,448.0	14,610.4	11,063.2	4097.5
1995	295,460.0	116,322.8	91,892.0	36,177.9	27,062.0	10,654.3
1996	360,126.8	142,907.5	119,768.8	47,527.3	34,072.8	13,520.9
1997	480,248.1	126,381.1	152,386.8	40,101.8	44,300.0	11,657.9
1998	453,492.0	119,340	123,596.9	32,525.5	39,227.8	10,323.1
1999	482,738.3	127,036.4	116,438.0	30,641.6	39,184.0	10,311.6
2000	512,714.7	134,924.9	109,409.8	28,792.1	36,876.0	9704.2
2001	529,735.5	139,404.1	121,811.1	32,055.6	41,025.2	10,796.1
2002	563,254.1	148,224.8	130,520.0	34,347.4	41,415.5	10,898.8
2003	629,975.3	165,782.9	141,911.0	37,345	44,103.6	11,606.2
2004	761,254.8	200,330.2	68,421.1	18,005.6	42,691.0	11,234.5
2005	745,357.7	197,184.6	–	–	128,371.5	33,960.7
2006	1,142,883.7	323,763.1	–	–	63,039.2	17,858.1
2007	1,447,540.5	437,323.4	–	–	85,586.6	25,857.0
2008	1,600,490.1	462,569.4	–	–	29,447.6	8510.9

Source: Bank Negara Malaysia.
Note: The finance companies assets and liabilities were absorbed by their respective commercial bank parents in 2005.

is considered a separate branch. On the other hand, foreign banks are afforded the same treatment as domestic banks in regard to money market instruments, access to the central bank discount window, and availability of offshore capital via swaps.

3. Review of the literature and hypothesis development

There is a wealth of research examining the impact of foreign ownership on bank efficiency. Banks expand internationally to gain from economies of scale, reduce risks, and garner higher profitability. However, in order to survive in foreign markets, foreign banks should possess some specific advantages which they can exploit cross-border (Casson, 1990). When these advantages can be transferred at little cost, or utilized at lower marginal cost, foreign banks may enjoy some competitive advantages relative to their domestic and other foreign bank counterparts (Lewis and Davis, 1987).

The empirical evidence to date seem to suggest that foreign owned banks in developing and transition countries have succeeded in capitalizing on their advantages and exhibit a higher level of efficiency compared to their domestic bank peers (e.g. Leightner and Lovell, 1998; Claessens et al., 2001; Isik and Hassan, 2002; Sathye, 2003; Micco et al., 2004; Ataullah et al. 2004; Shanmugam and Das, 2004; Bonin et al., 2005; Havrylchyk, 2006), but not so in less developed countries (Claessens et al., 2001). However, the earlier studies have not properly distinguished between the *home field advantage* and the *global advantage* hypothesis. One implication is that the empirical models may be mis-specified resulting in biased and misleading results (Berger et al., 2000).

To address this issue, Berger et al., (2000) proposes the *global advantage* hypothesis. Under the general form of the *global advantage* hypothesis, some efficiently managed foreign institutions are able to overcome any cross-border disadvantages and subsequently operate more efficiently than the domestic institutions in other nations. These organizations may have higher efficiency when operating in other nations by spreading their superior managerial skills or best-practice policies and procedures. They may also be able to raise revenues through superior investment or risk management skills by providing superior service quality/variety, or by obtaining diversification of risks which allows them to undertake higher risk-higher expected return investments.

Besides the general form of the global advantage hypothesis, Berger et al., (2000) also suggest the limited form of the *global advantage* hypothesis. Under the limited form of the *global advantage* hypothesis, only efficient institutions in one or a limited number of nations can operate more efficiently than domestic institutions in other nations. This could be due to among others differences in market environment, language, culture, super-

visory, and/or regulatory structure. In other words, the weight of proximity may be greater and the "liability of unfamiliarness" is more difficult to overcome for foreign banks headquartered in distant countries.

On the other hand, foreign banks with a common origin, either historical, linguistic, or both, can significantly reduce the costs of operating abroad while facilitating the exploitation of efficiencies or competitive advantages. A common origin may lead to advantages in product differentiation (Swoboda, 1990), knowledge transfer (Guillén and Tschoegl, 1999), and reduction in the cost of capital (local funds are easily obtained because of cultural proximities). In essence, it is safe to suggest that foreign banks headquartered within the same region with a similar market environment, language, culture, and supervisory and/or regulatory structure could be at better advantage compared to those located from distant countries. Accordingly, under the limited form of the *global advantage* hypothesis, we hypothesize the following

> H0: The relationship between efficiency and foreign banks from the Asian countries is positive after controlling for other bank specific traits and macroeconomic and financial markets condition variables.

3.1. Empirical evidence on the Malaysian banking sector

To date, studies by Sufian (2010b), Matthews and Ismail (2006), and Katib and Matthews (2000) are the most notable and closely related to the present paper. By employing the DEA method, Katib and Mathews (2000), examine the characteristics of the management structure and technical efficiency of the banking industry in Malaysia during 1989 to 1995. The results indicate that technical inefficiency in Malaysian banking was due to scale inefficiency. They suggest that banks with more market power (measured by their ratio of deposits to market deposits) tend to exhibit higher technical efficiency. Matthews and Ismail (2006), examine the technical efficiency and productivity of the Malaysian banking sector during the period 1994 to 2000. They find that the foreign banks have exhibited higher efficiency levels compared to their domestic bank counterparts. The results suggest that the efficient banks are characterized by size, but not profitability or loans quality.

More recently, Sufian (2010b), examines the efficiency of the Malaysian banking sector around the Asian financial crisis with the emphasis on the domestic versus foreign banks debate. He employed the non-parametric DEA method to compute the efficiency estimates of individual foreign and domestic banks in the sample. The empirical findings indicate that the foreign banks have exhibited higher technical efficiency levels compared to their domestic bank peers. Despite that the results seem to suggest that the foreign banks were severely affected by the Asian financial crisis, implying that the foreign banks were not insulated from unexpected events like the Asian financial crisis of 1997.

As mentioned earlier, these previous studies have not properly distinguished the *global advantage* hypothesis. Most importantly, to the best of our knowledge, within the context of the Malaysian banking sector, empirical studies employing the state of the art Simar and Wilson (1999), bias corrected DEA method is completely missing from the literature. In light of these knowledge gaps, this paper seeks to provide new empirical evidence on the impact of ownership and origins on the efficiency of banks operating in the Malaysian banking sector.

4. Data and methodology

We use annual bank level data of all Malaysian commercial banks over the period 1999 – 2008. The variables are obtained from published balance sheet information in annual reports of each individual bank. To maintain homogeneity, we only consider commercial banks in the analysis. Therefore, Islamic banks, investment banks, and specialized development banks are excluded from the sample. The total number of commercial banks operating in the Malaysian banking sector varied from 33 banks in 1999 to 22 banks in 2008 due to entry and exit of banks during the past decade. This gives us a total of 237 bank year observations. The sample represents the whole gamut of the industry's total assets.

4.1. Bootstrap data envelopment analysis

The non-parametric DEA method is employed to measure the technical efficiency of all banks operating in the Malaysian banking sector. For the purpose of this study, we adopt an input minimization orientation, based on the

assumption that during period under study banks strategically focus on reducing (or minimizing) costs. The DEA method involves constructing a non-parametric production frontier based on the actual input-output observations in the sample relative to which efficiency of each bank in the sample is measured (see Coelli et al., (1998) for a detailed review).

There are six main reasons why we adopt the DEA method. First, each DMU (bank in our case) is assigned a single efficiency score that allows ranking amongst the DMUs in the sample. Second, the DEA method highlights the areas of improvement for each single DMU such as either the input has been excessively used, or output has been under produced by the DMU (so they could improve on their efficiency). Third, there is a possibility of making inferences on the DMU's general profile – the DEA method allows for comparison to be made in regard to the production performance of each DMU to a set of efficient DMUs (called a reference set).[3] Fourth, the DEA method does not require a preconceived structure or specific functional form to be imposed on the data in identifying and determining the efficient frontier, error, and inefficiency structures of the DMUs (e.g. Evanoff and Israelvich, 1991; Grifell-Tatje and Lovell, 1997; Bauer et al., 1998). Fifth, the DEA method does not require standardization therefore allowing researchers to choose any kind of input and output of managerial interest (arbitrary), regardless of the different measurement units (Ariff and Can, 2008; Avkiran, 1999; Berger and Humphrey, 1997). Finally, the DEA method works fine with small sample sizes (Sufian and Habibullah, 2009).

To discuss DEA in more technical terms, let us assume that there is data on K inputs and M outputs for each N bank. For the ith bank, these are represented by x_i and y_i vectors respectively.

$$\hat{\delta}_i = \min_{\hat{\delta}_i, \lambda} \left\{ \delta > 0 | \hat{\delta}_i y_i \leq \sum_{i=1}^{n} y_i \lambda; x_i \geq \sum_{i=1}^{n} x_i \lambda; \lambda \geq 0 \right\}, \quad i = 1, \ldots, n \text{ banks} \tag{1}$$

where y is a vector of bank outputs, x is a vector of bank inputs, λ is a N x 1 vector of constants. The value of $\hat{\delta}_i$ is the technical efficiency score for the ith bank. A measure of $\hat{\delta}_i = 1$ indicates that the bank is technically efficient, while $\hat{\delta}_i > 1$ indicates that a bank is inefficient. The linear programming problem must be solved n times, once for each bank in the sample.

It is worth noting that the DEA model can be estimated by using either the constant returns to scale (CRS) or the variable returns to scale (VRS) assumptions. For the purpose of the present study, we employ the VRS assumption, since the CRS assumption is valid if all banks in the sample are operating at the optimal level of scale. However, technological advances and regulatory changes may have different impacts across banks of different sizes. In this vein, Assaf et al., (2011) points out that the VRS assumption permits modeling the entire range of technology.

4.2. Inputs and outputs specification

As in the most recent studies, (e.g., Isik and Hassan 2003; Sufian and Habibullah, 2009; Staub et al., 2010; Kamarudin et al., 2014a and Kamarudin et al., 2014b), we adopt the intermediation approach. Accordingly, three inputs and three output variables are chosen. The input vectors used are (X1) Total Deposits, (X2) Capital, and (X3) Labour, while, (Y1) Total Loans, (Y2) Investments, and (Y3) Non-Interest Income are the output vectors. Table 2[4] presents the summary of data used to construct the efficiency frontiers. All variables are measured in millions of Malaysian Ringgit (RM).

From Table 2 it can be observed that on average the domestic banks are about five times larger (in terms of asset size measured by fixed assets), command higher market share for both loans and deposits, have greater intensity towards loans financing, and employ more personnel relative to their foreign bank peers. From Table 2 it is apparent that the smallest domestic bank (in terms of asset size measured by fixed assets) is more than 15 times larger than the smallest foreign bank, while the largest domestic bank is 2.92 times larger in terms of fixed assets compared to the largest foreign bank operating in Malaysia during the period under study. It is

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[3] The owner of the DMUs may be interested to know which DMU frequently appears in this set. A DMU that appears more than others in this set is called the global leader. Apparently, the DMU owner may obtain a huge benefit from this information especially in positioning its entity in the market.

[4] As data on the number of employees are not readily made available, personnel expenses have been used as a proxy measure.

Table 2
Descriptive statistics for inputs, outputs, and input prices (RM million).

	Total loans (y1)		Investments (y2)		Non-Interest income (y3)		Total deposits (x1)		Personnel expenses (x2)		Fixed assets (x3)	
	Domestic banks	Foreign banks	Domestic banks Outputs	Foreign banks	Domestic banks	Foreign banks	Domestic banks	Foreign banks	Domestic banks Inputs	Foreign banks	Domestic banks	Foreign banks
Mean	33,194,892	7,624,858	9,009,079	2,458,007	525,642	171,197	43,340,497	10,636,042	376,044	93,672	396,140	79,239
Min	607,514	38,358	74,156	39,706.00	4448	14	869,577	187,254.00	17,170	3624	11,248	721
Max	138,985,721	56,023,787	36,423,398	12,660,382	4,602,143	1,052,576	182,169,861	62,429,470	1,452,403	497,368	1,419,973	486,179
Std. Dev.	31,263,963	9,655,003	8,609,216	2,846,240	703,128	215,167	40,893,457	12,745,865	348,054	116,366	354,824	109,239

Note: Y1: Loans (includes loans to customers and other banks), Y2: Investments (includes dealing and investment securities), Y3: Non-Interest Income (defined as fee income and other non-interest income, which among others consist of commission, service charges and fees, guarantee fees, and foreign exchange profits), X1: Total Deposits (includes deposits from customers and other banks), X2: Capital (measured by the book value of property, plant, and equipment), X3: Personnel Expenses (inclusive of total expenditures on employees such as salaries, employee benefits and reserve for retirement pay).
The table presents means and standard deviations of Malaysian banks input and output variables used to construct the DEA frontiers during the period 1999 to 2008

also worth noting that on average the domestic owned banks have a higher proportion of investments (3.67 times) and generates greater income from non-interest sources (3.07 times) compared to their foreign owned bank peers.

4.3. Bootstrap regression analysis

It is of considerable interest to examine environmental factors or variables influencing the efficiency scores derived from the DEA method. The most commonly used are the one-step and the two-step approaches. In the one-step approach, environmental variables are included directly in the estimation of efficiency whereas in the two-step approach efficiency scores obtained in the first stage of analysis are then regressed on a number of bank-specific environmental variables. Both approaches are employed in the literature.

The one-step approach seems to be the preferred choice if using a parametric approach to the efficiency evaluation, following the maximum likelihood procedure of Battese and Coelli (2005). The two step approach, on the other hand seems to be the favored approach if efficiency is estimated by means of DEA. In a typical two-stage study, the relative efficiency of each bank is first evaluated and then regressed on a set of internal (bank specific characteristics) and external (macroeconomic and industry specific) variables.

By using the bias-corrected technical efficiency score as the dependent variable, we estimate the following baseline regression model:

$$\hat{\delta}_{i,t} = \beta_1 \sum_{n=33}^{6} Bank\ Characteristics_{i,t} + \beta_2 \sum_{n=10}^{5} Macro\ \&\ Financial\ Market_t + \beta_3 \sum_{n=33}^{6} Origin_{i,t} + \varepsilon_{i,t} \qquad (2)$$

Where $\hat{\delta}_{i,t}$ is the bias-corrected technical efficiency score derived from the DEA bootstrapped method, *Bank Characteristics* is a vector of bank specific characteristics, *Macro & Financial Market* is a set of macroeconomics and financial market conditions and *Origins* is set of bank origins variables, ε is the error term, and the subscripts '*i*' and '*t*' represents individual bank and time period, respectively.[5] Please refer Appendix A for further discussion on bootstrap DEA.

4.4. Environmental variables

The environmental variables used to explain bank efficiency are grouped under four main characteristics. The first represent bank specific characteristics, the second encompass economic and financial market conditions during the period of examination, and the third is a set of bank origins dummy variables. Specifically, we include six bank specific variables in the regression models namely LLP/TL (loans loss provisions divided by total loans), NII/TA (non-interest income divided by total assets), NIE/TA (non-interest expenses divided by total assets), LOANS/TA (total loans divided by total assets), LNTA (log of total assets), and EQASS (book value of stockholders' equity as a fraction of total assets).

The LLP/TL variable is included in the regression analysis as a proxy of credit risk (see Miller and Noulas, 1997). Following Sufian (2009) among others, we introduce the NII/TA variable in the regression analysis as a proxy measure of bank diversification into non-traditional activities. The NIE/TA variable is used to provide information on the variations of bank operating costs (see Pasiouras, 2008; Sufian, 2009). The LOANS/TA variable in included the regression models to capture for the impact of liquidity risk. Following Hauner (2005), among others, the LNTA variable is included in the regression models as a proxy of size. Finally, the EQASS variable is included in the regression models to examine the relationship between efficiency and bank capitalization (see Pasiouras, 2008; Kosmidou, 2008; Sufian, 2009).

To measure the relationship between economic and market conditions and bank efficiency, we introduce GDP (gross domestic products), INFL (the rate of inflation), CR3 (the concentration ratio of the three largest banks in terms of assets), Z-Score (Z-SCORE), and MKTCAP/GDP (the ratio of stock market capitalization over GDP) variables in the regression models. The GDP variable is introduced in the regression model to control for cyclical output effects. We include INFL to control for macroeconomic risk. Following Pasiouras (2008) and Kosmidou

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[5] Following De Bandt and Davis(2000) and Staikouras et al. (2008) among others, the log-linear form is chosen as it typically improves the regression's goodness of fit and may reduce simultaneity bias.

Table 3
Descriptive of the variables used in the Bootstrap regressions.

Variable	Description	Mean	Std. Dev.	Sources/Database
	Dependent			
LN(TE)	Natural log of the bias-corrected technical efficiency derived from the DEA method.	0.120	0.156	Authors' own calculation
	Independent			
	Internal Factors			
LN(LLP/TL)	Natural log of loan loss provisions/ total loans. An indicator of credit risk, which shows how much a bank is provisioning in year t relative to its total loans.	−2.228	0.421	Banks' annual financial statements
LN(EQASS)	A measure of bank's capital strength in year t, calculated as the natural log of equity/ total assets.	−1.617	0.335	Banks' annual financial statements
LN(NIE/TA)	Calculated as the natural log of non-interest expense/ total assets and provides information on the efficiency of the management regarding expenses relative to assets in year t.	−4.385	0.618	Banks' annual financial statements
LN(NII/TA)	A measure of bank's diversification towards non-interest income, computed as the natural log of non-interest income over total assets.	−4.637	0.559	Banks' annual financial statements
LN(LOANS/TA)	A measure of bank's loans intensity calculated as the natural log of total loans divided by total assets.	−0.782	0.672	Banks' annualfinancial statements
LN(TA)	The natural log of the accounting value of bank j's total assets in year t.	16.411	1.507	Banks' annual financial statements
	External Factors			
LN(GDP)	The natural log of gross domestic products.	11.750	1.051	IMF International Financial Statistics.
LN(INFL)	The natural log of the rate of inflation.	0.836	0.504	IMF International Financial Statistics.
LN(CR3)	The natural log of the three largest banks asset concentration ratio.	−0.802	0.158	IMF International Financial Statistics.
LN(Z-SCORE)	The natural log of the z-score and is used as a proxy measure of the banking sector's risk to default.	2.384	0.289	IMF International Financial Statistics.
LN(MKTCAP/GDP)	The natural log of the stock market capitalization divided by GDP ratio. The variable serves as a proxy of financial development.	0.392	0.140	IMF International Financial Statistics.
	Bank Origins			
DUMAMER	A dummy variable that takes a value of 1 for foreign banks from the North America, 0 otherwise.	NA	NA	Authors' own calculation.
DUMEURO	A dummy variable that takes a value of 1 for foreign banks from the European countries, 0 otherwise.	NA	NA	Authors' own calculation.
DUMASIA	A dummy variable that takes a value of 1 for foreign banks from the Asian countries, 0 otherwise.	NA	NA	Authors' own calculation.

(2008) among others, the CR3 variable is entered in the regression models as a proxy variable for the banking sector's concentration. The Z-SCORE variable is used as a proxy of bank soundness. Following among others Ben Naceur and Omran (2011), we use MKTCAP/GDP as a measure of the size of the equity market.

Table 3 presents the summary statistics of the dependent and independent variables.

The information on the degree of correlation between the explanatory variables used in the panel regression analysis is given in Table 4. The matrix shows that in general the correlation between the bank specific variables is not strong suggesting that multicollinearity problems are not severe (see Kennedy (2008) for further discussions).

5. Empirical findings

5.1. Efficiency in the Malaysian banking sector

Panels A and B of Table 5 contains the VRS technical efficiency estimates of the domestic and foreign banks obtained from 2000 bootstrap iterations.[6] We use the FEAR software (see Wilson, 2006) to write the programme. To conserve space, we do not report the original (non-bootstrapped) DEA scores in the paper.[7] The present study constructs and analyzes results from dynamic panels (multi frontier analysis), which is critical in a dynamic business environment as a bank may be the most efficient in one year, but may not be in the following year(s). A dynamic panel may highlight any significant changes taking place in the Malaysian banking sector during the period under study and enables us to observe a bank more than a time during the sample period.

The results in Panel A of Table 5 clearly indicate that the mean technical efficiency of the domestic banks range from a low of 73.7% during the year 1999 to a high of 94.4% during the year 2002. During the period under study, we find that RHB Bank, Southern Bank, and EON Bank are the most technically efficient domestic banks. On the other hand, the least efficient domestic banks are Hock Hua (Sabah) Bank, Wah Tat Bank, and Sabah Bank. It is also worth highlighting that these three banks have failed and were acquired during the year 2000.

Turning to examine the efficiency of the foreign owned banks, the empirical findings in Panel B of Table 4 seem to suggest that the foreign banks have exhibited a mean technical efficiency (inefficiency) of 90.0% (10.0%). By examining the technical efficiency of each bank, we find that Bank of America, ABN-Amro Bank, and Bank of Nova Scotia are the least efficient foreign banks, while OUB Bank, OCBC Bank, and Bank of China are the most technically efficient foreign banks operating in the Malaysian banking sector.

It is also interesting to note that the most efficient foreign banks in Malaysia originate from other Asian countries with similar language and culture providing support to the *liability of unfamilianess* hypothesis (see Berger et al., 2000). To recap, the *liability of unfamiliarness* hypothesis posits that the weight of proximity is greater and more difficult to overcome for foreign banks headquartered in distant countries due to differences in market environments, languages, cultures, supervisory, and regulatory structures.

5.2. Determinants of bank efficiency

Table 6 present the bootstrap regression results. The empirical findings seem to suggest that the coefficient of the NII/TA variable is always positive, implying that Malaysian banks which derived a higher proportion of its income from non-interest sources tend to report higher efficiency levels. However, the result should be interpreted with caution since the coefficient of the variable is only statistically significant at the 10% level and when we control for other macroeconomic and market condition variables in the regression model.

During the period under study, the estimates show that technical efficiency increases with size, a fact that support the results of Hauner (2005), among others. Hauner (2005), offers two potential explanations for which size could positively influence bank efficiency. First, if it relates to market power, large banks should pay less for their inputs. Second, there may be increasing returns to scale through the allocation of fixed costs over a higher volume of services, or efficiency gains from a specialized workforce. The result comes as no surprise given that the Malaysian financial sector is relatively underdeveloped and that significant economies of scale could be achieved with the increase in size.

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[6] To obtain a reliable bootstrap estimates Simar and Wilson (1998) recommended the use of 2000 bootstrap iterations. We have also performed similar regression analysis by using 1,000 and 3,000 iterations. In essence the results remain robust in terms of directions and significance levels. The routine for the panel data analysis is written by using the STATA software.

[7] The original DEA estimates (non-bootstrapped), the bias levels, and the upper and lower bounds for each bank in the sample are available upon request from the authors. In essence, the results indicate efficiency bias in the range of 0.0126 (Public Bank in 2006) to 0.2982 (Bank of Tokyo in 1999).

Table 4
Correlation matrix for the explanatory variables.

	LNLLP/TL	LNNII/TA	LNNIE/TA	LNLOANS/TA	LNTA	LNEQASS	LNGDP	LNINFL	LNMKTCAP/GDP	LNCR3	LNZ-SCORE
LNLLP/TL	1.000										
LNNII/TA	−0.224**	1.000									
LNNIE/TA	0.136*	0.307**	1.000								
LNLOANS/TA	0.410**	−0.315**	0.019	1.000							
LNTA	0.221**	−0.037	0.055	0.327**	1.000						
LNEQASS	−0.283**	0.124	−0.137*	−0.313**	−0.638**	1.000					
LNGDP	−0.332**	0.066	−0.235**	−0.256**	0.260**	−0.001	1.000				
LNINFL	−0.173**	−0.104	0.023	−0.016	0.097	−0.019	0.432**	1.000			
LNMKTCAP/GDP	−0.065	−0.119	−0.044	−0.087	0.063	−0.110	0.275**	0.136*	1.000		
LNCR3	−0.003	−0.102	0.084	−0.094	0.067	−0.095	0.248**	0.215**	0.622**	1.000	
LNZ-SCORE	−0.218**	0.029	−0.143*	−0.140*	0.140*	0.036	0.598**	0.441**	−0.268**	−0.323**	1.000

Note: The table presents results from Spearman ρ correlation coefficients.

** and * indicate significance at 1% and 5% levels, respectively.

The notation used in the table below is defined as follows: LNLLP/TL is the natural log of loan loss provisions/ total loans; LNNIE/TA is calculated as the natural log of non-interest expense/ total assets; LNNII/TA is computed as the natural log of non-interest income over total assets; LNLOANS/TA is as the natural log of total loans divided by total assets; LNTA is the natural log of the accounting value of banks total assets; LNEQASS is calculated as the natural log of equity/ total assets; LNGDP is natural log of gross domestic products; LNINFL is the natural log of the rate of inflation; LNMKTCAP/GDP is the natural log of the stock market capitalization divided by GDP ratio; LNCR3 is the natural log of the three largest banks asset concentration ratio; LNZ-SCORE is the natural log of the Z-Score.

Table 5
The Bootstrapped efficiency results in Malaysian banking sector: 1999–2008.

Bank	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	Mean efficiency
Panel A: domestic banks											
AFFIN BANK	0.818	0.843	0.883	0.949	0.909	0.877	0.854	0.815	0.825	0.854	0.863
ALLIANCE BANK	0.810	–	0.965	0.872	0.931	0.886	0.854	0.863	0.935	0.853	0.885
ARAB-MALAYSIAN BANK	0.778	0.911	0.911	0.964	0.906	0.984	0.968	0.963	0.945	0.946	0.928
BAN HIN LEE BANK	0.782	–	–	–	–	–	–	–	–	–	0.782
BANK UTAMA	0.854	0.893	0.925	0.966	–	–	–	–	–	–	0.910
BSN COMMERCIAL BANK	0.751	–	–	–	–	–	–	–	–	–	0.751
CIMB BANK	0.729	0.920	0.957	0.966	0.924	0.969	0.941	0.958	0.938	0.946	0.925
EON BANK	0.880	0.960	0.958	0.973	0.951	0.976	0.901	0.900	0.914	0.911	0.932
HOCK HUA BANK (SABAH)	0.323	–	–	–	–	–	–	–	–	–	0.323
HOCK HUA BANK	0.728	–	–	–	–	–	–	–	–	–	0.728
HONG LEONG BANK	0.782	0.914	0.936	0.957	0.923	0.921	0.943	0.908	0.929	0.814	0.903
MAYBANK	0.707	0.916	0.913	0.965	0.892	0.970	0.942	0.958	0.934	0.946	0.914
ORIENTAL BANK	0.738	0.836	–	–	–	–	–	–	–	–	0.787
PHILEO ALLIED BANK	0.875	–	–	–	–	–	–	–	–	–	0.875
PUBLIC BANK	0.850	0.876	0.950	0.858	0.892	0.891	0.902	0.964	0.938	0.945	0.907
RHB BANK	0.817	0.942	0.954	0.976	0.931	0.971	0.959	0.959	0.920	0.945	0.937
SABAH BANK	0.588	–	–	–	–	–	–	–	–	–	0.588
SOUTHERN BANK	0.902	0.965	0.936	0.936	0.900	0.969	0.940	–	–	–	0.936
PACIFIC BANK	0.733	–	–	–	–	–	–	–	–	–	0.733
WAH TAT BANK	0.288	–	–	–	–	–	–	–	–	–	0.288
Mean Efficiency	0.737	0.907	0.935	0.944	0.916	0.941	0.920	0.921	0.920	0.907	0.905
Std. Dev.	0.164	0.043	0.025	0.041	0.019	0.043	0.041	0.054	0.037	0.052	0.041
Panel B: Foreign Banks											
ABN AMRO BANK	0.603	0.703	0.799	0.965	0.928	0.970	0.939	0.960	0.484	0.944	0.830
BANGKOK BANK	0.702	0.917	0.915	0.936	0.941	0.970	0.941	0.959	0.942	0.939	0.916
BANK OF AMERICA	0.385	0.647	0.513	0.966	0.600	0.970	0.941	0.959	0.905	0.948	0.783
BANK OF CHINA	–	–	0.917	0.965	0.888	0.970	0.940	0.960	0.907	0.945	0.937
BANK OF NOVA SCOTIA	0.702	0.913	0.911	0.965	0.554	0.970	0.941	0.960	0.912	0.945	0.877
BANK OF TOKYO	0.902	0.939	0.948	0.970	0.884	0.949	0.833	0.970	0.933	0.954	0.928
CITIBANK	0.775	0.914	0.922	0.965	0.866	0.969	0.941	0.961	0.970	0.951	0.923
DEUTSCHE BANK	0.762	0.918	0.918	0.965	0.886	0.968	0.943	0.967	0.909	0.947	0.918
HONGKONG BANK	0.840	0.873	0.950	0.941	0.956	0.970	0.768	0.958	0.853	0.798	0.891
JP MORGAN CHASE	0.703	0.914	0.957	0.976	0.895	0.969	0.943	0.958	0.908	0.946	0.917
OCBC BANK	0.926	0.912	0.945	0.966	0.862	0.970	0.949	0.937	0.946	0.971	0.938
OUB BANK	0.956	0.926	–	–	–	–	–	–	–	–	0.941
STANDARD CHARTERED BANK	0.876	0.943	0.933	0.967	0.858	0.969	0.941	0.960	0.935	0.946	0.933
UOB BANK	0.868	0.894	0.842	0.872	0.886	0.970	0.887	0.960	0.952	0.973	0.910
Mean Efficiency	0.769	0.878	0.882	0.955	0.846	0.968	0.916	0.959	0.889	0.939	0.900
Std. Dev.	0.156	0.092	0.120	0.027	0.124	0.006	0.055	0.007	0.125	0.044	0.055

Note: Detailed results are available from the authors upon request.

We find that the level of capitalization (EQASS) is positively related to the efficiency of banks operating in the Malaysian banking sector, providing support to the argument that well capitalized banks face lower costs of going bankrupt, thus reduce their cost of funding. Furthermore, strong capital structure is essential for banks in developing economies, since it provides additional strength to withstand financial crises and increased safety for depositors during unstable macroeconomic conditions (Sufian 2010a). Moreover, lower capital ratios in banking imply higher leverage and risk and therefore higher borrowing costs. Thus, it is reasonable for the better capitalized banks to exhibit higher efficiency levels. In contrast to Sufian (2010b), who employs the standard DEA and a multivariate Tobit regression analysis, the empirical findings from this study indicate that credit risk (LLP/TL), overhead expenses (NIE/TA), and liquidity (LOANS/TA) are not statistically significant in explaining the variations in the efficiency of banks operating in the Malaysian banking sector.

Table 6
Bootstrap second stage regression analysis.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
CONSTANT	−0.662***	−0.274	0.266	−0.298	−0.428*	−0.286
	(−3.07)	(−1.26)	(−1.28)	(−1.25)	(−1.82)	(−1.17)
			Bank Specific			
LN(LLP/TL)	0.051	0.036	0.036	0.039	0.032	0.038
	(1.18)	(0.77)	(0.70)	(0.73)	(0.67)	(0.69)
LN(NII/TA)	0.033	0.038*	0.037	0.033	0.031	0.034
	(1.36)	(1.64)	(1.60)	(1.48)	(1.34)	(1.52)
LN(NIE/TA)	−0.040	−0.035	−0.036	−0.038	−0.028	−0.038
	(−1.37)	(−1.22)	(−1.28)	(−1.15)	(−1.06)	(−1.14)
LN(LOANS/TA)	−0.013	0.004	0.001	0.007	−0.020	0.004
	(−0.59)	(0.17)	(0.03)	(0.28)	(−0.71)	(0.15)
LN(TA)	0.054***	0.043***	0.042***	0.044***	0.051***	0.044***
	(3.58)	(2.92)	(2.91)	(2.85)	(3.30)	(2.57)
LN(EQASS)	0.160***	0.134**	0.135***	0.145**	0.102**	0.143**
	(3.10)	(2.51)	(2.61)	(2.42)	(2.00)	(2.25)
		Macroeconomic and Market				
LN(GDP)		−0.013	−0.013	−0.013	−0.019*	−0.013
		(−1.38)	(−1.37)	(−1.44)	(−1.89)	(−1.36)
LN(INFL)		−0.011	−0.011	−0.010	−0.008	−0.010
		(−0.50)	(−0.49)	(−0.48)	(−0.38)	(−0.48)
LN(CR3)		0.493***	0.495***	0.498***	0.479***	0.498***
		(3.28)	(3.35)	(3.21)	(3.16)	(3.26)
LN(Z-SCORE)		0.205***	0.204***	0.203***	0.199***	0.203***
		(4.56)	(4.61)	(4.62)	(4.53)	(4.57)
LN(MKTCAP/GDP)		−0.405***	−0.408***	−0.406***	−0.408***	−0.408***
		(−2.89)	(−2.95)	(−2.78)	(−2.90)	(−2.89)
		Origins				
DUMAMER		−0.018			−0.013	
		(−0.53)			(−0.36)	
DUMEURO				0.021		0.002
				(0.65)		(0.44)
DUMASIA					0.079***	
					(3.00)	
No. of observations	237	237	237	237	237	237
R^2	0.167	0.265	0.266	0.266	0.292	0.267
Wald χ^2 statistics	14.72**	47.77***	47.94***	48.01***	46.42***	48.14***
No. of iterations	2000	2000	2000	2000	2000	2000

Note: The dependent variable is the bias-corrected technical efficiency derived from the DEA method. LLP/TL is a measure of bank's credit risk, calculated as the ratio of total loan loss provisions divided by total loans. NII/TA is a measure of bank's diversification towards non-interest income, calculated as total non-interest income divided by total assets. NIE/TA is a measure of bank management quality calculated as total non-interest expenses divided by total assets. LOANS/TA is a measure of bank's loans intensity calculated as the ratio of total loans to bank total assets. TA is the size of the bank's total asset measured as total bank assets. EQASS is a measure of banks capitalization measured by banks total shareholders' equity divided by total assets. GDP is the gross domestic product. INFL is the rate of inflation. CR3 is the three largest banks asset concentration ratio. Z-SCORE is a proxy measure of the banking sector's risk to default. MKTCAP/GDP is the ratio of stock market capitalization and serves as a proxy of financial market development. DUMAMER is a dummy variable that takes a value of 1 for foreign banks from the North America, 0 otherwise. DUMEURO is a dummy variable that takes a value of 1 for foreign banks from the European countries, 0 otherwise. DUMASIA is a dummy variable that takes a value of 1 for foreign banks from the Asian countries, 0 otherwise.
Values in parentheses are *z*-statistics.
***, **, and * indicate significance at 1, 5 and 10% levels.

Turning to the impact of macroeconomic and financial market conditions, we find that in most cases the coefficient of the GDP variable is negative. The result to a certain extent provides support to the view that high economic growth improves business environment and lowers bank entry barriers. This would result in competition to intensify and consequently dampens banks' profitability (Liu and Wilson 2011). In all cases, the results should

be interpreted with caution since the coefficient of the variable is only statistically significant at the 10% level and when we control for foreign banks originating from the Asian countries in the regression models.

Concerning the impact of banking sector's concentration, it can be observed that the coefficient of the three banks concentration ratio (CR_3) exhibits a positive sign and is statistically significant at the 1% level in all regression models estimated. The empirical findings clearly lend support to the Structure-Conduct-Performance (SCP) hypothesis. To recap, the SCP hypothesis states that banks in a highly concentrated market tend to collude and therefore earn monopoly profits (Molyneux et al., 1996).

Interestingly, we find that the impact of banking sector risk (Z-SCORE) is positive. The result is in consonance with the findings of among others Boyd and De Nicolo (2006), lending support to the stringent capital requirements of Basel II. From the policymaking point of view, the findings seem to call for a more effective policymaker's role in reducing excessive bank risk exposures and at the same time induce a more efficient risk management by banks. It can be observed from Table 6 that the impact of stock market capitalization (MKTCAP/GDP) is negative on Malaysian banks' efficiency levels (statistically significant at the 1% level in all cases). The results clearly advocate that during the period under study, the Malaysian stock market serves as a substitute rather than complementing the products and services that banks offers to borrowers in Malaysia.

5.3. Does bank origins matter?

Berger et al., (2005) suggests that foreign owned banks from developed nations in developing countries may have access to superior technologies, particularly information technologies for collecting and assessing "hard" quantitative information.[8] However, in less developed countries or regions the weight of proximity is greater, thus the *liability of unfamiliarness* is more difficult to overcome. Local communities differ in terms of the economic, institutional, social, and cultural characteristics from regions where out-of-region bank holding companies are headquartered. Therefore, the risk of being isolated from strategic banking functions requiring staffs that are more qualified is higher.

For the reasons mentioned above, it is safe to assume that foreign banks headquartered in distant countries with different market environments, languages, cultures, and supervisory and/or regulatory structure could be at disadvantage compared to those located within the Asian region. In essence, any specific advantage that the foreign banks are likely to have over their domestic bank peers are likely to accrue to the foreign banks headquartered in the Asian region. This could be attributed to shorter distances from the home country and similarity in languages and cultures.

To address this concern and unlike the previous studies on bank efficiency, we take into account the home country of the foreign owned banks in order to test for the "limited form" of the *global advantage* hypothesis. Accordingly, we repeat equation (2) to further classify foreign banks operating in the Malaysian banking sector into three major groups. It is worth noting that when we add the other group of variables to the baseline specification that include the bank specific attribute variables, the coefficients of the baseline variables continued to remain robust in terms of directions and significance levels. Therefore, we will only discuss the results of the new variables added to the baseline specification. The regression results are presented in columns 3 – 6 of Table 6.

It can be observed from column 5 of Table 6 that technical efficiency is positively related to the foreign banks from the Asian countries (statistically significant at the 1% level). On the other hand, we do not find statistically significant impact of DUMAMER and DUMEURO. In essence, the result which suggests that banks from the Asian countries to be relatively more efficient compared to their domestic bank peers, clearly rejects the *home field advantage* hypothesis, but lend support to the "limited form" of the *global advantage* and the *liability of unfamiliarness* hypotheses.

Berger et al., (2000) suggest that under the "limited form" of the *global advantage* hypothesis, only efficient institutions in one or a limited number of nations with specific favourable market or regulatory conditions in their home countries can operate more efficiently than domestic banks in other nations. In a recent study, Havrylchyk (2006), suggests that Dutch banks have been the most efficient banking group operating in Poland, thus supporting the "limited form" of the *global advantage* hypothesis.

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[8] Interested readers are referred to Berger et al (2000) and Berger et al. (2005) for detailed discussions on the *Home Field*, *Global Advantage*, and *Liability of Unfamiliarness* hypotheses.

6. Concluding remarks

The present study investigates the efficiency of the Malaysian banking sector during 1999–2008. The efficiency estimates of individual banks are evaluated by using the DEA method. We employ a bootstrapped regression analysis to examine the impact of ownership and origins on bank productive efficiency, while controlling for other bank specific traits such as size, profitability, capitalization, and credit risk. The empirical findings from the DEA method indicate an increase in efficiency of the Malaysian banking sector over the sample period.

The results from the bootstrap regression analysis suggest that productive efficiency is positively related to size, non-interest income, and capitalization. The empirical findings seem to suggest positive impact of the banking sector's concentration and risk on the efficiency of banks operating in the Malaysian banking sector. During the period under study, the impact of stock market capitalization seems to be negative on Malaysian banks' technical efficiency, implying that the Malaysian stock market offers substitution possibilities, rather than complementing the products and services offered by banks to borrowers in Malaysia. We find that banks from the Asian countries to be relatively more efficient compared to foreign banks from other regions and their domestic bank peers, rejecting the *home field advantage* hypothesis, but lend support to the "limited form" of the *global advantage* and the *liability of unfamiliarness* hypotheses.

Based on the empirical findings, several policy implications can be drawn in respect to the efficiency of banks in foreign markets. First, the empirical findings from this study clearly indicate that the ability to overcome disadvantages of being foreign and to compete successfully in foreign markets varies between banks and origins. Resources, capabilities, and managerial know how are bank specific. Caves (1971), points out that multinational firms expanding abroad must cultivate their unique mix of strategic assets to compensate for their foreigner status. Consequently, international market success depends on the ability of a firm to understand the chances and challenges of the new environment, adapt resources, structures, and processes to leverage internal assets for host country competitive advantage (Luo et al., 2002). Therefore, the concept of liability of foreignness does not imply that foreign banks are automatically doomed abroad, but that they should be prepared for an uphill battle.

Second, domestic banks may have distinct advantages over their foreign counterparts because of the intensive accumulation of tacit knowledge in economic, social, legal, and cultural conditions in their home country market. In contrast, foreign banks may face problems to develop deep understanding of the host country's cultural and social regulations and their impact (Jensen and Szulanski, 2004). Given these social and cultural roots of liability of foreignness, moving operations abroad is typically more of a marathon than a sprint i.e. it takes time to compete on the same level as local enterprises. In this regard, Zaheer and Mosakowski (1997), suggest that it takes more than 15 years for foreign firms to overcome the disadvantage of being foreign in the currency trading industry, while DeYoung and Hasan (1998), indicate that De Novo banks require nine years to catch-up with the established banks in terms of efficiency.

Due to its limitations, the paper could be extended in a variety of ways. First, the scope of this study can be further extended to examine changes in cost efficiency over time. Second, future research into the efficiency of the Malaysian banking sector could also consider the production function along with the intermediation function. Third, investigation of changes in productivity over time as a result of technical change or technological progress or regress by employing the bootstrap Malmquist Productivity Index (MPI) could yet be another extension to the paper.

Despite these limitations, the findings of this study are expected to contribute significantly to the existing knowledge on the operating performance of the Malaysian banking sector. Nevertheless, the study has also provided further insight to the bank's specific management as well as the policymakers with regard to attaining optimal utilization of capacities, improvement in managerial expertise, efficient allocation of scarce resources, and the most productive scale of operation of the banks in the industry. This may also facilitate directions for sustainable competitiveness of Malaysian banking operations in the future.

Appendix A

Simar and Wilson (1998, 1999) argued that efficiency scores generated by the DEA method are strongly dependent on each other in the statistical sense. Thus, by using the DEA scores in a second-stage regression might violate the basic model assumption required by the regression models. They also suggest that the DEA efficiency

score is a relative efficiency index and not an absolute one. To address this issue, Simar and Wilson (1998), proposed a double bootstrap procedure, which enables consistent inference in the second-stage regression models. The bootstrap method is based on the idea of re-sampling from the original data in order to assign statistical properties for the quantities of interest. More recently, Simar and Wilson (2007), extended their approach to account for the impact of environmental variables on productive efficiency.[9] Before illustrating their procedure we first present the following model:

$$\hat{\delta}_i = z_i\beta + \varepsilon_i \tag{A.2}$$

Where $\hat{\delta}_i$ is a bias corrected estimates of efficiency scores of bank i at time t, z_i is a vector of environmental variables that explain the productive efficiency between the banks under consideration and β refers to a vector of parameters with some statistical noise ε_i. Simar and Wilson (2007), suggest that naïve regression models may lead to estimation problems due to correlation and dependency problems of the efficiency scores which may violate the regression assumption that ε_i are independent of z_i. The importance of the Simar and Wilson (2007), procedure is that it produces bias-corrected estimates of $\hat{\delta}_i$ and therefore valid estimates of the parameters in the regression model.

The double bootstrapping process can be summarized as follows:

(1) Calculate the DEA input-oriented efficiency score $\hat{\delta}_i$ for each bank using the linear programming in (1).
(2) Use the maximum likelihood method to estimate the truncated regression of $\hat{\delta}_i$ on z_i to provide and estimate $\hat{\beta}$ of β and an estimate $\hat{\sigma}_s$ of σ_s.
(3) For each bank $i=1, \dots, n$, repeat the next four steps (1 – 4) B times to yield a set of bootstrap estimates $\{\hat{\delta}^*_{i,b}, b = 1, \dots, B\}$.
　i. Draw ε_i from the $N(0, \hat{\sigma}^2_\varepsilon)$ distribution with left truncation at $(1 - \hat{\beta}z_i)$.
　ii. Compute $\hat{\delta}^*_i = \hat{\beta}z_i + \varepsilon_i$
　iii. Construct pseudo data set (x^*_i, y^*_i), where $(x^*_i = x_i)$ and $(y^*_i = y_i\hat{\delta}_i/\delta^*_i)$.
　iv. Compute a new DEA estimate $\hat{\delta}^*_i$ on the set of pseudo data (x^*_i, y^*_i), i.e.
(4) For each bank, compute the bias corrected estimate $\widehat{\hat{\delta}}_i = \hat{\delta} - \hat{bias}_i$, where $\hat{bias}_i$ is the bootstrap estimator of bias obtained as $\hat{bias}_i = \frac{1}{B}\sum_{b=1}^{B}\hat{\delta}^*_{i,b} - \hat{\delta}_i$.
(5) Use the maximum likelihood method to estimate the truncated regression of $\widehat{\hat{\delta}}_i$ on z_i, providing estimates $(\widehat{B}, \widehat{\hat{\sigma}})$ of (B, σ_ε).
(6) Repeat the next three steps (1 – 3) B_2 times to obtain a set of bootstrap estimates $\{(\widehat{B}^*_b, \widehat{\hat{\sigma}}^*_b, b = 1, \dots B_2)\}$.
　i. For $i=1, \dots n$, ε_i is drawn from $N(0, \widehat{\hat{\sigma}})$ with left truncation at $(1 - \widehat{\hat{\beta}}z_i)$.
　ii. For $i=1, \dots n$, compute $\delta^{**}_i = \widehat{\hat{\beta}}z_i + \varepsilon_i$.
　iii. The maximum likelihood method is again used to estimate the truncated regression of δ^{**}_i on z_i, providing estimates $(\widehat{\hat{\beta}}^*, \widehat{\hat{\sigma}}^*)$.
(7) Use the bootstrap results to construct confidence intervals.

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9 These are variables that are neither inputs nor outputs, but are used to mainly explain the variation in the efficiency scores.

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