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RESEARCH ARTICLE

The impact of ownership structure on bank productivity and efficiency: Evidence from semi-parametric Malmquist Productivity Index

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Abstract: The present study employs the state of the art bias-corrected Malmquist Productivity Index method to examine the sources of efficiency and productivity of the foreign and domestic banks operating in the Malaysian banking sector. The preferred methodology enables us to isolate efforts to catch up to the frontier (efficiency change) from shifts in the frontier (technological change [TECHCH]). The results indicate that the Malaysian banking sector has exhibited productivity progress mainly attributed to technological progress. The empirical findings suggest that both the domestic and foreign banks have exhibited productivity progress albeit at different quantum attributed mainly to progress in TECHCH.

Keywords: banks, total factor productivity, bootstrap Malmquist Productivity Index, Malaysia

JEL classifications: G21, G28

1. Introduction

Banking firms have heterogeneous ownership, corporate, market and risk characteristics (Isik & Hassan, 2002). While the choice of ownership i.e. foreign, local, public, private, state, etc., is important within the context of non-bank financial institutions, it becomes crucial in the context of a bank (Boubakri, Cosset, Fischer, & Guedhami, 2005) and is an essential element for the development of a healthy banking system in developing countries (Lang & So, 2002). To date, a growing number of studies have examined the relationship between ownership structure and bank efficiency and productivity (e.g. Grigorian & Swedberg, 2006; Havrylchyk, 2006; Sufian, 2011). However, most of the available studies on the ownership–performance relationship have concentrated on the US and banking sectors of the western and developed countries (Berger & Mester, 1997). In this vein, De (2003) points out that the absence of a well-defined market for corporate control and weak property rights, evidence from the developed countries are not directly applicable to the developing countries banking sectors. Furthermore, evidence from the US banking sector may not be comprehensive due to the lack of state owned banks in the country (Altunbas, Evans, & Molyneux, 2001).

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By employing data on the whole gamut of foreign and domestic banks, the present study attempts to build on the earlier studies on the performance of the banking sector in a developing economy and examine sources of total factor productivity (TFP): efficiency change (EFFCH) or technological change (TECHCH). The period under study, which coincides with the period of financial sector liberalization in Malaysia is a perfect setting to examine the performance of different forms of bank ownership. The earlier study by D'souza and Megginson (1999) suggests that the inefficiency of the state-owned banks in many countries only become perceptible when they are forced to compete with the newly arriving domestic and foreign institutions. Therefore, detecting the extent and sources of inefficiency (waste of resources) in each banking organizational form is crucial in the new competitive environment for policy and research concerns.

The paper also attempts to critically investigate and to test whether banks with dominant foreign ownership outperform their domestic bank peers. Although empirical studies performed to examine this issue are vast in the developed countries, evidence on the developing countries is relatively sparse (Berger & Mester, 1997). Therefore, there is a need to examine if these results are applicable to different settings (Williams, 1998). Furthermore, the Malaysian banking sector provides an interesting ground on account that although it is a developing country, some of the foreign banks operating in the country's banking sector originates from developing countries as well (e.g. Thailand and China).

To do so, we employ the state of the art Simar and Wilson (1999) bias-corrected Malmquist Productivity Index (MPI) method to compute the TFP of the domestic and foreign banks operating in the Malaysian banking sector. The preferred methodology enables us to isolate efforts to catch up to the frontier (EFFCH) from shifts in the frontier (TECHCH). To the best of our knowledge, the present study will be the first to examine the efficiency and productivity of the Malaysian banking sector by employing the bias-corrected MPI method. Unlike the previous studies focusing on the Malaysian banking sector, the present study adopts a dynamic panel of the MPI method. Isik and Hassan (2002) suggest that the dynamic panel is more flexible and thus more appropriate than estimating a single multi-year frontier for banks in the sample. Furthermore, as suggested by Banker and Natarajan (2008), we also test the null hypothesis (the foreign owned banks are relatively more productive than the domestic owned banks) against the alternative hypothesis (the domestic owned banks are relatively more productive than the foreign owned banks).

This paper is set out as follows: the following section reviews the main literature, while in Section 3 we outline the approaches to the measurement of efficiency and productivity changes. Section 4 discusses the results and we conclude in Section 5.

2. Review of related literature

The literature examining the efficiency and productivity of financial institutions with parametric and/or non-parametric frontier techniques has expanded rapidly in recent years. The liberalization of the banking sector and the increasing number of bank failures in the 1980s and early 1990s contributed to an increasing academic interest in the topic. However, a large body of literature spanning the past century exists on the US banking sector (Berger, 2007; Berger & Humphrey, 1997; Berger, Hunter, & Timme, 1993; Berger & Mester, 2003), while relatively few has been conducted within the context of the developing countries banking sectors (Berger & Humphrey, 1997).

Lensink, Meesters, and Naaborg (2008) suggest that a foreign bank is usually defined as a bank of which more than 50% of the shares are owned by non-domestic residents. This indicates that a bank may be a domestic bank in one country, but a foreign bank everywhere else. For example, Citibank is a domestic bank in the US but it will be as a foreign bank in all other countries. Berger and Humphrey (1997) examine the efficiency on 130 of financial institutions, of which a few address the impact of foreign ownership. They find that the relative efficiency of foreign vs. domestic ownership appears to depend on host and home country conditions.

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According to Sufian (2007), the results from the Data Envelopment Analysis (DEA) suggest that Malaysian Islamic banks efficiency declined in year 2002 to recover slightly in years 2003 and 2004. The domestic Islamic banks were more efficient compared to the foreign Islamic banks albeit marginally. The source of inefficiency of Malaysian Islamic banks in general has been scale, suggesting that Malaysian Islamic banks have been operating at the wrong scale of operations.

Studies on the X-efficiency of foreign owned banks in the US have generally found that they were relatively inefficient compared to their domestically owned bank peers (Miller & Parkhe, 2002). According to these studies, the foreign owned banks have to trade efficiency, both cost and profit, for rapid expansion of market share as they financed their rapid growth by relying on purchased funds, which are relatively more expensive than core deposits. Berger, DeYoung, Genay, and Udell (2000) home field advantage hypothesis suggest that domestic financial institutions are relatively more efficient than financial institutions from foreign nations attributed to the fact that it is less efficient for these institutions to operate from a distance. The lack of exposure and training in lesser-known markets and the lack of close monitoring by the management of the banks in their home countries are some of the adverse factors that may offset foreign banks potential to exploit any comparative cost advantage. In other words, there may be some costs associated with transferring comparative advantages to a new market where more time and investment is required to deal with the idiosyncratic features of the local customers and service delivery systems.

Despite the poor performance of the foreign owned banks in developed countries, a growing body of empirical evidence has shown the superiority in performance of the foreign owned banks in developing and transition economies. Foreign owned banks in India were found to be relatively efficient compared to the domestically owned banks (e.g. Ataullah, Cockerill, & Le, 2004). Similarly, Sathye (2003) and Shanmugam and Das (2004) also suggest that the public and foreign owned banks in India have exhibited a higher level of technical efficiency compared to their private owned bank peers. Leightner and Lovell (1998) find that on average Thai banks have experienced falling TFP growth, while the average foreign banks have exhibited increasing TFP.

Hasan and Marton (2003) find that foreign owned banks in Hungary have been relatively more profit efficient compared to their domestic bank counterparts. Likewise, in a study on the Czech and Poland banking sectors, Weill (2003) find that the foreign owned banks are more efficient than the domestic banks. By employing data from a wide range of transition countries, Grigorian and Swedberg (2006) find that foreign ownership with controlling power and enterprise restructuring enhance commercial bank efficiency. Isik and Hassan (2002) suggest that foreign banks in Turkey, especially the foreign bank branches are significantly more X-efficient compared to their domestic bank peers.

Berger, Clarke, Cull, Klapper, and Udell (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. 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. The risk of being isolated from strategic banking functions requiring staffs that are more qualified is therefore higher.

Isik and Hassan (2002) studied the impact of different ownership and organizational structures on the efficiency of the Turkish banking industry over the period 1988–1996 by using a series of parametric and non-parametric techniques. They found that the foreign banks operating in Turkey were relatively more efficient rather than domestic counterparts, while private banks were found to be more efficient relative to public banks for all efficiency measures.

Most of the previous studies such as DeYoung and Nolle (1996), Miller and Parkhe (2002), and Havrylchyk (2006) summarize that foreign banks in transition and developing markets show higher efficiency than their domestically owned counterparts. In developed countries, foreign banks are reported to be at a disadvantaged position relative to their domestic counterparts.

The above literature reveals the following research gaps. First, the majority of these studies concentrate on the banking sectors of the developed countries, such as the US, Europe, and other developed countries banking sectors. Second, empirical evidence on the developing and emerging countries banking sectors are relatively scarce. Finally, to the best of our knowledge, empirical evidence employing the state of the art Simar and Wilson (1999) bias-corrected MPI method is completely missing from the literature. In the light of these knowledge gaps, this paper seeks to provide for the first time new empirical evidence on the sources of total factor productivity change (TFPCH) in the Malaysian banking sector by using the bias-corrected MPI method.

3. Methodology and data

3.1. Data envelopment analysis

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 firm in the sample is measured (Coelli, 1996). The DEA method can be described as follows:

Consider N observations on Decision-Making Units (DMUs). Each observation, DMU ($j=1,2, \ldots , n$), uses m inputs x_{ij} ($i=1,2, \ldots , m$) in order to produce s outputs y_{rj} ($r=1,2, \ldots , s$). Select a DMU to be examined for relative efficiency and for convenience of notations, denote this DMU as DMU_0. The mathematical programming problem to be solved can then be formalized in ratio form as follows:

$$\max h_o(u,v)=\frac{\sum_{r=1}^{s} u_r y_{ro}}{\sum_{i=1}^{m} v_i x_{io}} \quad \text{subject to the constraints} \tag{1}$$

$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1, \quad j=1,2,\ldots, \quad j_o,\ldots,n \tag{2}$$

$$u_r \geq 0, \quad r=1,2,\ldots,s \tag{3}$$

$$v_i \geq 0, \quad i=1,2,\ldots,m \tag{4}$$

where x_{ij} is the observed amount of input i for the DMU_j, $x_{ij}<0, i=1,2,\ldots,n, j=1,2,\ldots,n$. y_{rj} stands for the observed amount of output r for DMU_j, $y_{rj}<0, r=1,2,\ldots,s, j=1,2,\ldots,n$. The optimal solution to the above mathematical programming problem provides a set of "virtual multipliers" $\{v_i\}$ for inputs and "virtual multipliers" $\{u_r\}$ for outputs for DMU_0. The weighted input $\left(\sum_{i=1}^{m} v_i x_{ij}\right)$ and output $\left(\sum_{r=1}^{s} u_r y_{rj}\right)$ values are, respectively, called the "virtual input" and "virtual output" for the DMU under investigation. The weights are not pre-determined, but instead by using mathematical programming to determine the best set of weights represented by values that maximize the efficiency score for each DMU_0 to be evaluated. The value of the objective function at the optimum is interpreted as a measure of the relative efficiency of the DMU being evaluated relative to all DMUs where each is represented as a ratio of virtual output to input. The resulting efficiency is always non-negative and less than, or equal to one. A DMU is said to be relatively efficient if the maximized score in its objective value is one. It is otherwise deemed to be inefficient.

Since the above problem has an infinite number of solutions, Charnes, Cooper, and Rhodes (1978) transformation is used to arrive at a linear programming problem that is equivalent to the above linear fractional programming problem (Zhu, 2009).

By setting $\sum_{i=1}^{m} v_i x_{io} = 1$, the problem becomes:

$$\max z_o = \sum_{r=1}^{s} u_r y_{ro} \quad \text{subject to the constraints} \tag{5}$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0, \quad j = 1,2, \ldots, n \tag{6}$$

$$\sum_{i=1}^{m} v_i x_{io} = 1 \tag{7}$$

$$u_r \geq 0, \quad r = 1,2, \ldots, s \tag{8}$$

$$v_i \geq 0, \quad i = 1,2, \ldots, m \tag{9}$$

There are two main approaches for the estimation of the efficient frontier from these *n* observations. Firstly, the input oriented models seek to find the amount that the inputs are to be proportionally decreased given a certain amount of output. And secondly, the output oriented models reveal the amount that the outputs are to be proportionately increased given a certain amount of input. Since we define efficiency as the proportional reduction in inputs possible for a given level of output in order to obtain the efficient use of inputs, we follow the input minimization to find the most efficient bank(s) in the Malaysian banking sectors. Therefore, the dual model for the linear programming model is as follows (Zhu, 2009):

$\theta^* = \min \theta$ subject to the constraints;

$$\sum_{j=1}^{n} \lambda_j x_{ij} \leq \theta x_{io} \quad i = 1,2, \ldots, m \tag{10}$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{ro} \quad r = 1,2, \ldots, s \tag{11}$$

$$\sum_{j=1}^{n} \lambda_j = 1 \tag{12}$$

$$\lambda_j \geq 0 \quad j = 1,2, \ldots, n \tag{13}$$

where x_{io} is the *i*th input and y_{ro} is the *r*th output for DMU_0. Here, the optimal value satisfies the condition $\theta^* \leq 1$. θ^* is the (input oriented) efficiency score of DMU_0. If $\theta^* = 1$, the input levels can no longer be reduced proportionally and DMU_0 is on the efficient frontier, i.e. there is no other DMUs that operate more efficiently than this DMU. This is an envelopment model with variable returns to scale (VRS).

Since the above optimization problem is performed for each DMU separately, DEA provides a collection of best virtual multipliers, one set for each DMU. This is to say that the DEA methodology is directed toward each individual DMU, as opposed to regression techniques which are directed toward average behavior over all DMUs. The virtual multipliers derived for each DMU are constructed in a manner that gives the specific DMU under investigation (DMU_0) the highest possible efficiency score, subject to the provision that no other DMU can be labeled as "super efficient" (have an efficiency score greater than one) using the same optimal virtual multipliers. This allows firms having different strategic objectives to prioritize their desired outputs (have different virtual multipliers) and still be compared to each other with respect to their efficiency, provided that all of the firms have the same inputs and outputs.

It is also worth noting that if the restriction $\sum_{j=1}^{n} \lambda_j = 1$ is removed from Equation 10, the model becomes a constant returns to scale (CRS) model in which the frontier exhibits CRS. On the other hand, if this restriction is replaced with $\sum_{j=1}^{n} \lambda_j \leq 1$, then it is called non-increasing returns to scale envelopment model. The model will be called a non-decreasing returns to scale envelopment model if the condition is replaced with $\sum_{j=1}^{n} \lambda_j \geq 1$ (Zhu, 2009).

3.2. Malmquist Productivity Index

Three different indices are frequently used to evaluate TFPCH: the Fischer (1922), Tornqvist (1936), and Malmquist (1953) indices.[1] The non-parametric (Malmquist) and parametric (Fischer and Tornqvist) indices differ in several ways in respect to their behavioral assumptions and whether or not they recognize random errors in the data (noise). Grifell-Tatjé and Lovell (1996) suggest that the MPI has several distinct advantages over the Fischer and Tornqvist indices.

Firstly, it does not require the profit maximization or the cost minimization assumption. Secondly, it does not require information on the input and output prices. Thirdly, if the researcher has panel data, it allows the decomposition of productivity changes into two components (technical efficiency change or catching up and technical change or changes in the best practice). Finally, unlike the parametric methods, it does not require specifying the functional form for the frontier, which could be biased due to specification errors if the functional form is misspecified. Its main disadvantage is the necessity to compute the distance functions. However, the DEA method can be used to solve this problem.

Following Färe, Grosskopf, Norris, and Zhang (1994) among others, the present study adopts the output oriented MPI. The analysis employs the notion of an output distance function first proposed by Shephard (1970), which measures how much a unit's outputs can be proportionately increased given the observed levels of its inputs. The structure of the production technology is assumed to exhibit CRS. We delineate the structure of production technology with the output distance function as follows:

$$D^t\left(x_j^t, y_j^t\right) = \min\left\{\phi | \left(x_j^t, y_j^t/\phi\right) \in P^t\right\} \tag{14}$$

which measures the output technical efficiency of bank j at time t relative to the technology at time t (Shephard, 1970). Since technical efficiency is measured relative to the contemporaneous technology, we have $D^t\left(X_j^t, Y_j^t\right) \leq 1$, with $D^t\left(X_j^t, Y_j^t\right) = 1$ signifying that bank j is on the production frontier and is technically efficient, while $D^t\left(X_j^t, Y_j^t\right) < 1$ indicating that the bank is below the frontier and is technically inefficient.

Before describing the MPI method, we need to define distance functions with respect to two different time periods. The efficiency of bank j at time t relative to the technology at time $t+1$ is represented by

$$D^{t+1}\left(x_j^t, y_j^t\right) = \min\left\{\phi | \left(x_j^t, y_j^t/\phi\right) \in P^{t+1}\right\} \tag{15}$$

Similarly, the efficiency of bank j at time $t+1$ relative to the technology at time t is defined by the distance function

$$D^t\left(x_j^{t+1}, y_j^{t+1}\right) = \min\left\{\phi | \left(x_j^{t+1}, y_j^{t+1}/\phi\right) \in P^t\right\} \tag{16}$$

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Caves et al. (1982) define the MPI as

$$M^{t}\left(x_{j}^{t+1},y_{j}^{t+1},x_{j}^{t},y_{j}^{t}\right)=\frac{D^{t}(x_{j}^{t+1},y_{j}^{t+1})}{D^{t}(x_{j}^{t},y_{j}^{t})}$$
or
$$M^{t+1}\left(x_{j}^{t+1},y_{j}^{t+1},x_{j}^{t},y_{j}^{t}\right)=\frac{D^{t+1}(x_{j}^{t+1},y_{j}^{t+1})}{D^{t+1}(x_{j}^{t},y_{j}^{t})} \tag{17}$$

The indices in Equation 17 provide measures of productivity changes. To avoid choosing an arbitrary benchmark, two continuous MPI are combined into a single index by computing the geometric mean and then multiplicatively decomposed this index into two sub-indices measuring changes in technical efficiency and technology as follows (Färe, Grosskopf, Lindgren, & Roos, 1989, 1992).

$$\Delta\text{Eff}^{t,t+1}=\frac{D_{c}^{t+1}\left(x_{j}^{t+1},y_{j}^{t+1}\right)}{D_{c}^{t}\left(x_{j}^{t},y_{j}^{t}\right)} \tag{18}$$

and

$$\Delta\text{Tech}^{t,t+1}=\left[\frac{D_{c}^{t}\left(x_{j}^{t+1},y_{j}^{t+1}\right)}{D_{c}^{t+1}\left(x_{j}^{t+1},y_{j}^{t+1}\right)}\times\frac{D_{c}^{t}\left(x_{j}^{t},y_{j}^{t}\right)}{D_{c}^{t+1}\left(x_{j}^{t},y_{j}^{t}\right)}\right]^{1/2} \tag{19}$$

The ratio in Equation 18 is an index of technical efficiency change between period t and $t+1$, measuring whether bank j moves closer to, or farther away from best practices during the time period. The value of $\Delta\text{Eff}^{t,t+1}$ is greater than, equal to, or less than unity depending on whether the relative efficiency of bank j improved, unchanged, or declined during the period. The term $\Delta\text{Tech}^{t,t+1}$ in Equation 19 is an index of technology change, which gives the geometric mean of two ratios. A value of $\Delta\text{Tech}^{t,t+1}$ greater than, equal to, or less than unity indicates progress, no change, or regress in technology, respectively, between periods t and $t+1$.

From Equations 18 and 19, the relationship between the MPI and its two sub-indices is

$$M^{t,t+1}=\Delta\text{Eff}^{t,t+1}\times\Delta\text{Tech}^{t,t+1} \tag{20}$$

Clearly, productivity change is the decomposition of changes in both efficiency and technology with $M^{t,t+1}$ greater than, equal to, or less than unity representing progress, stagnation, or regress in TFP, respectively, between periods t and $t+1$. In principle, one may calculate the MPI in Equation 20 relative to any technology pattern. The CRS technology is adopted to compute the MPI and its two sub-indices in the preceding analysis.

The $\Delta\text{Eff}^{t,t+1}$ index can be further disaggregated into its mutually exhaustive components of pure technical efficiency change (PEFFCH) $\Delta\text{PureEff}^{t,t+1}$ calculated relative to the VRS technology and a component of scale efficiency change (SECH) $\Delta\text{Scale}^{t,t+1}$ capturing changes in the deviation between the VRS and CRS technologies. That is,

$$\Delta\text{Eff}^{t,t+1}=\Delta\text{PureEff}^{t,t+1}\times\Delta\text{Scale}^{t,t+1} \tag{21}$$

where

$$\Delta\ \text{PureEff}^{t,t+1}=\frac{D_{v}^{t+1}\left(x_{j}^{t+1},y_{j}^{t+1}\right)}{D_{v}^{t}\left(x_{j}^{t},y_{j}^{t}\right)} \tag{22}$$

$$\Delta\,\text{Scale}^{t,t+1}=\frac{D_c^{t+1}\left(x_j^{t+1},y_j^{t+1}\right)/D_v^{t+1}\left(x_j^{t+1},y_j^{t+1}\right)}{D_c^{t}\left(x_j^{t},y_j^{t}\right)/D_v^{t}\left(x_j^{t},y_j^{t}\right)} \tag{23}$$

and the subscripts v and c denote VRS and CRS technologies, respectively. $\Delta\,\text{PureEff}^{t,t+1}<1$ indicates an increase in pure technical efficiency, while $\Delta\,\text{PureEff}^{t,t+1}<1$ indicates a decrease and $\Delta\,\text{PureEff}^{t,t+1}=1$ indicates no change in pure technical efficiency. Similarly, $\Delta\,\text{Scale}^{t,t+1}<1$ implies that the most efficient scale is increasing over time, so the scale efficiency is improving, while $\Delta\,\text{Scale}^{t,t+1}<1$ implies the opposite, and $\Delta\text{Scale}^{t,t+1}=1$ indicates that there is no change in scale efficiency.

3.3. Bootstrapping the MPI

Simar (1992) and Simar and Wilson (1998) are pioneers in using the bootstrap in frontier models to obtain non-parametric envelopment estimators. The idea behind bootstrapping is to approximate a true sampling distribution by mimicking the data generating process (DGP). The procedure is based on constructing a pseudo sample and re-solving the DEA model for each DMU with the new data. Repeating this process many times enables us to build a good approximation of the true distribution. Simar and Wilson (1998) show that the statistically consistent estimation of such confidence intervals very much depends on the consistent replication of a DGP. In other words, the most important problem of bootstrapping in frontier models relates to the consistent mimicking of the DGP.[2] They argued that this problem refers to the bounded nature of the distance functions. Since the distance estimation values are close to unity, re-sampling directly from the set of original data (the so-called naive bootstrap) to construct pseudo samples will provide an inconsistent bootstrap estimation of the confidence intervals.

Hence, to overcome this problem, they propose a smoothed bootstrap procedure. They use a univariate kernel estimator of density of the original distance function estimates (for efficiency scores in that case), and then construct the pseudo data from this estimated density. However, to estimate the Malmquist indices, we have panel data instead of a single cross-section of data with the possibility of temporal correlation. Thus, Simar and Wilson (1999), in adapting the bootstrapping procedure for Malmquist indices, propose a consistent method using a bivariate kernel density estimate via the covariance matrix of data from adjacent years. However, the estimated distance functions $\hat{D}_{it_1|t_1}$ and $\hat{D}_{it_2|t_2}$ using a kernel estimator are bounded from above unity and it is noted by Simar and Wilson (1999) that a bivariate kernel estimator value under this condition is biased and asymptotically inconsistent. To account for this issue, Simar and Wilson (1998, 1999) adapt a univariate reflection method proposed by Silverman (1986).[3] Therefore, to achieve consistent replication of the DGP taking all of these features into account, one must use the smoothed bootstrap. Repeatedly re-sampling from the Malmquist indices via the smoothed bootstrap results in a mimic of the sampling distribution of the original distance functions (a set of bootstrap Malmquist indices), from which confidence intervals can be constructed. The process can be summarized as follows:

(1) Calculation of the Malmquist index $\hat{M}_i^o(t_1, t_2)$ for each bank ($i=1, \ldots, N$) in each time (t_1 and t_2) by solving the linear programming models 8 and 9 and their reversals.

(2) Construction of the pseudo data-set $\{(x_{it}^*, y_{it}^*); i=1,\ldots,N; t=1,2\}$ to create the reference bootstrap technology using the bivariate kernel density estimation and adoption of the reflection method proposed by Silverman (1986).

(3) Calculation of the bootstrap estimate of the Malmquist index ${}^*\hat{M}_i^o(t_1,t_2)$ for each bank ($i=1, \ldots, N$) by applying the original estimators to the pseudo sample attained in Step 2.

(4) Repeating Steps 2–3 for a large number of B times (in this study $B=2000$) to facilitate B sets of estimates for each bank.

(5) Construct the confidence intervals for the Malmquist indices.

The basic idea designed for construction of the confidence intervals of the Malmquist indices is that the distribution of $\hat{M}_i^o(t_1,t_2) - M_i^o(t_1,t_2)$ is unknown and can be approximated by the distribution of ${}^*\hat{M}_i^o(t_1,t_2) - \hat{M}_i^o(t_1,t_2)$, where $M_i^o(t_1,t_2)$ is the *true* unknown index, $\hat{M}_i^o(t_1,t_2)$ is the estimate of the Malmquist index, and ${}^*\hat{M}_i^o(t_1,t_2)$ is the bootstrap estimate of the index. Hence, a_α and b_α defining the $(1-\alpha)$ confidence interval:

$$\Pr\left(b_\alpha \le \hat{M}_i^o(t_1,t_2) - M_i^o(t_1,t_2) \le a_\alpha\right) = 1-\alpha \tag{24}$$

can be approximated by estimating the values a_α^* and b_α^* given by:

$$\Pr\left(b_\alpha^* \le {}^*\hat{M}_i^o(t_1,t_2) - \hat{M}_i^o(t_1,t_2) \le a_\alpha^*\right) = 1-\alpha \tag{25}$$

Thus, an estimated $(1-\alpha)$ percentage confidence interval for the *i*th Malmquist index is given by:

$$\hat{M}_i^o(t_1,t_2) + a_\alpha^* \le M_i^o(t_1,t_2) \le \hat{M}_i^o(t_1,t_2) + b_\alpha^* \tag{26}$$

The Malmquist index for the *i*th bank is said to be significantly different from unity (which would indicate no productivity change), at α% level, if the interval in Equation 26 does not include unity. With the information provided, it is possible to ascertain whether productivity growth (or decline) measured by the MPI is significant i.e. whether it is greater than (or less than) unity at the desired levels of significance. The same holds for the sources of TFPCH as it is now possible to assess the significance of both EFFCH and TECHCH if they occur.

It should be noted that by using the calculated bootstrap value in Step 4, we can also correct for any finite-sample bias in the original estimators of the Malmquist indices. We only need to apply a simple procedure outlined by Simar and Wilson (1999) as follows:

The bootstrap bias estimate for the original estimator $\hat{M}_i^o(t_1,t_2)$ is:

$$\widehat{bias}_B\left[\hat{M}_i^o(t_1,t_2)\right] = B^{-1}\sum_{b=1}^{B} {}^*\hat{M}_i^o(t_1,t_2)(b) - \hat{M}_i^o(t_1,t_2)$$

Thus, a bias-corrected estimate of $M_i^o(t_1,t_2)$ can be computed as:

$$\tilde{M}_i^o(t_1,t_2) = \hat{M}_i^o(t_1,t_2) - \widehat{bias}_B\left[\hat{M}_i^o(t_1,t_2)\right] = 2\hat{M}_i^o(t_1,t_2) - B^{-1}\sum_{b=1}^{B} {}^*\hat{M}_i^o(t_1,t_2)(b) \tag{28}$$

However, as explained by Simar and Wilson (1999), the bias-corrected estimator may have a higher mean-square error than the original estimator, and hence it will be less reliable. Overall, the bias-corrected estimator should only be considered if the sample variance ${}^*s_i^2$ of the bootstrap values $\left\{{}^*\hat{M}_i^o(t_1,t_2)(b)\right\}_{b=1,\dots,B}$ is less than a third of the squared bootstrap bias estimate for the original estimator, that is:

$${}^*s_i^2 < \frac{1}{3}\left(\widehat{bias}_B\left[\hat{M}_i^o(t_1,t_2)\right]\right)^2 \tag{29}$$

3.4. Hypothesis tests

Banker (1993) and Banker and Natarajan (2004, 2008) suggest that the DEA score is a consistent estimator. Thus, as suggested by Banker and Natarajan (2008), we proceed to test the null hypothesis (the foreign owned banks are relatively more productive than the domestic owned banks) against the alternative hypothesis (the domestic owned banks are relatively more productive than the foreign owned banks). Following Banker (1993) and Banker and Natarajan (2004, 2008) among others, we employ the following DEA-based statistics:

(i) If the true productivity $\hat{M}$ is distributed as exponential over [0, ∞] for the two groups i.e. foreign owned banks and the domestic owned banks, then under the null hypothesis that there is no difference between the two groups and the two sub-periods, the test statistics is calculated as

$$T\exp = \left[\sum_{j\in N1}(\hat{M}-1)/N1\right] / \left[\sum_{j\in N2}(\hat{M}-1)/N2\right] \tag{30}$$

which is evaluated by the F-distribution with ($2N1/2N2$) degrees of freedom, where $N1$ and $N2$ are the number of sample banks.

(ii) If no such assumptions are maintained about the probability distribution of efficiency and productivity, a non-parametric Kolmogorov–Smirnov's test statistics given by the maximum vertical distance between $F^{G1}(\hat{M})$ and $F^{G2}(\hat{M})$, the empirical distributions of $\hat{M}$ for sub-groups G_1 and G_2 respectively, is used. This statistic, by construction, takes values between 0 and 1 and a high value for this statistic is indicative of significant difference in inefficiency between the two groups.

(iii) In addition, as suggested by Banker, Zheng, and Natarajan (2010), we also employ the Mann–Whitney [Wilcoxon] test, to examine the difference in the efficiency and productivity of the foreign owned and the domestic owned banks. The Mann–Whitney's U statistic is given by

$$\hat{U} = \sum_{i=1}^{N1}\sum_{j=1}^{N2}\hat{D}_{ij} \tag{31}$$

Mann and Whitney (1947) show that for large samples of $N1$ and $N2$ (for $N1$ and $N2$ as small as 6), U is normally distributed with mean $N1\times N2/2$ and variance $N1\times N2\times(N+1)/12$, where $N=N1+N2$. Thus, the large sample test statistics is

$$\hat{Z} = \frac{\hat{U} - N1N2/2}{N1N2(N+1)/12} \tag{32}$$

The formal two hypotheses are as follows:

H1: The foreign owned banks are relatively more productive than the domestic owned banks.

H1A: The domestic owned banks are relatively more productive compared to the foreign owned banks.

3.5. Specification of bank inputs and outputs

The DEA-based MPI requires bank inputs and outputs whose choice is always an arbitrary issue (Berger & Humphrey, 1997). In the banking theory literature, there are two main approaches competing with each other in this regard: the production and intermediation approaches (Sealey & Lindley, 1977). Under the production approach, pioneered by Benston (1965), a financial institution is defined as a producer of services for account holders, that is, they perform transactions on deposit accounts and process documents such as loans. The intermediation approach on the other hand assumes that financial firms act as an intermediary between savers and borrowers, and posits total loans and securities as outputs, whereas deposits along with labor and physical capital are defined as inputs.

Elyasiani and Mehdian (1990) suggest three advantages of the intermediation approach over other approaches. They suggest that (1) it is more inclusive of the total banking cost as it includes interest expense on deposits and other liabilities; (2) it appropriately categorizes deposits as inputs; and (3) it has an edge over other definitions for data quality considerations. Furthermore, Berger and Humphrey (1997) point out that the production approach might be more suitable for branch efficiency studies, as at most times bank branches basically process customer documents and bank funding, while investment decisions are mostly not under the control of branches. Therefore, as in

Table 1. Descriptive statistics for inputs, outputs, and input prices

	Loans ($y1$)		Investments ($y2$)		Non-interest income ($y3$)		Total deposits ($x1$)		Capital ($x2$)		Labor ($x3$)	
	DB	FB	DB	FB	DB	FB	DB	FB	DB	FB	DB	FB
Min	607.5	38.4	74.2	39.7	4.4	−87.8	869.6	187.3	17.2	3.6	11.2	.7
Mean	33,178.3	7,624.9	9,079.1	2,458.0	522.5	171.2	43,399.2	10,636.0	374.3	93.7	396.9	79.2
Max	138,985.7	56,023.8	36,423.4	12,660.4	4,602.1	1,052.6	182,169.9	62,429.5	1,452.4	497.4	1,419.9	486.2
S.D	31,120.7	9,655.0	8,601.1	2,846.2	700.7	215.2	40,710.1	12,745.9	346.9	116.4	353.3	109.2

Source: Banks annual reports and authors own calculations.

Notes: $y1$: 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).

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

majority of the empirical literature (Bader, Mohammed, Ariff, & Hassan, 2008; Isik & Hassan, 2002; Kamarudin, Nordin, Muhammad, & Hamid, 2014; Kamarudin, Nordin, & Nasir, 2013; Sufian, Kamarudin, & Noor, 2012, 2013), we adopted a modified version of intermediation approach as opposed to the production approach for selecting input and output variables to construct the TFP frontiers.

Accordingly, Malaysian banks are regarded as intermediary between savers and borrowers, producing three outputs namely, *Total loans* ($y1$), which include loans to customers and other banks, *Investments* ($y2$), which include investment securities held for trading, investment securities available for sale (AFS), and investment securities held to maturity, and *Non-interest income* ($y3$), by employing three inputs namely, *Total deposits* ($x1$), which include deposits from customers and other banks, *Capital* ($x2$), measured as the book value of property, plant and equipment, and *Labor* ($x3$), which is inclusive of total expenditures on employees such as salaries, employee benefits, and reserve for retirement pay.

Table 1 presents the summary statistics of the output and input variables used to construct the productivity frontiers. All the variables are measured in millions of Malaysian Ringgit (RM). It is apparent that on average the domestic banks are about four times larger (in terms of physical capital), command higher market share for both loans and deposits, have greater intensity towards loans financing, and employ more personnel compared to their foreign bank counterparts. From Table 1 it is also clear that the smallest domestic bank (in terms of physical capital) is more than four times larger than the smallest foreign bank, while the largest domestic bank is 2.9 times larger in terms of physical capital compared to the largest foreign bank operating in the Malaysian banking sector.

3.6. Data

This paper uses data on all commercial banks operating in the Malaysian banking sector during the period 1998–2008. Our source of data is the income statements and balance sheets of the respective banks for the years observed. The primary source for financial data was obtained from the Bank Scope database produced by the Bureau van Dijk, which provides the banks' balance sheets and income statements. Bank Scope database contains specific data on 25,800 banks worldwide, including commercial banks in Malaysia. Furthermore, Bank Scope database presents the original currencies' data of the specific countries and provides the option to convert the data to any other currencies. This study used Ringgit Malaysia (RM) currency for purposes of standardizing the data, particularly of financial figures since the sample of the research is cover on the Malaysian banks. The total number of commercial banks operating in Malaysia varied from 32 banks in 1998–1999 to 22 banks in 2008. The number of observations varied across time due to entry and exit of banks during the years. This gives us a total of 234 bank year observations, which represents 100% of banks operating in the Malaysian banking sector during the period.

4. Results and discussion

In this section, we will discuss the sources of the Malaysian banking sector's productivity changes measured by the bias-corrected MPI and assign changes in TFPCH to TECHCH and EFFCH. We will also attempt to attribute change in EFFCH to changes in PEFFCH and/or SECH. Because the year 1998 is the reference year, the MPI and its components takes an initial score of 1.000. Hence, any score greater (lower) than 1.000 in subsequent years indicates progress (regress) in the relevant measures. It is worth mentioning that favorable EFFCH is interpreted as evidence of "catching up" to the frontier, while favorable TECHCH is interpreted as innovation (Cummins, Weiss, & Zi, 1999). The summary of annual means for the industry, domestic, and foreign banks' TFPCH, TECHCH, EFFCH, and its decomposition into PEFFCH and SECH for the years 1998–2008 are presented in Panels A, B, and C of Table 2, respectively.

4.1. Productivity of Malaysian banks and its decompositions

As depicted in Panel A of Table 2, the MPI results indicate that the Malaysian banking sector has on average exhibited TFPCH progress of 9.7%.[4] The results seem to suggest that Malaysian banks have exhibited TFPCH regress during all years ranging from a low of 1.5% during the year 2001 to a high of 17.8% during the year 2004. During the period under study, the 9.7% progress in TFPCH of the Malaysian banking sector could be attributed mainly to the 7.1% increase in EFFCH. On the other hand, it can be observed from Panel A of Table 2 that the EFFCH of Malaysian banks seem to have increased at a slower rate of 1.2%. The decomposition of the EFFCH index into its PEFFCH and SECH components indicate that the source of the increase in Malaysian banks' EFFCH was mainly attributed to scale rather than pure technical efficiency. The results imply that Malaysian banks have been operating at the optimal scale of operations, but have been managerially inefficient in controlling their operating costs.

Panel B of Table 2 presents the results for the domestic banks. During the period under study, the findings seem to suggest that the domestic banks have exhibited progress in TFPCH by 9.5%. The decomposition of the TFPCH index into its TECHCH and EFFCH components indicate that the progress in the domestic banks' TFPCH were solely attributed to the 4.9% increase in TECHCH. On the other hand, the domestic banks' EFFCH seem to have increased by a slower rate of 2.7% during the period under study. The decomposition of the EFFCH index into its PEFFCH and SECH components suggest that the dominant source of the increase in the domestic banks' EFFCH were mainly attributed to managerial rather than scale. This implies that although the domestic banks have been managerially efficient in controlling their operating costs, they have been operating at the non-optimal scale of operations.

We next turn to discuss the foreign banks results. The empirical findings presented in Panel C of Table 2 seem to suggest that the foreign banks' TFPCH have increased by 9.6%, a slightly faster rate compared to their domestic bank counterparts. Similar to their domestic bank peers, the decomposition of the TFPCH index into its TECHCH and EFFCH components indicate that the 5.3% increase in TECHCH has largely contributed to the foreign banks' TFPCH progress. On the other hand, the foreign banks seem to have exhibited EFFCH increase of 4.1%. In contrast to EFFCH, the foreign banks seem to have exhibited TECHCH progress during most of the years under study. The favorable condition has resulted in the foreign banks to exhibit increase in EFFCH. The decomposition of the EFFCH index into its PEFFCH and SECH components indicate that the dominant source of the increase in the foreign banks' EFFCH were mainly scale rather than managerially related. If anything could be delved, the results clearly indicate that the foreign banks have been operating at the optimal scale of operations, but were managerially inefficient in controlling their operating costs.

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Table 2. Bootstrap MPI decompositions

Banks	Bias corrected TFPCH index	Bias corrected TECHCH index	Bias corrected EFFCH index	Bias corrected PEFFCH index	Bias corrected SECH index
Panel A: ALL_BNKS					
1998	1.000	1.000	1.000	1.000	1.000
1999	1.090	1.108	.984	.982	1.002
2000	1.148	1.146	1.001	1.001	1.000
2001	1.015	1.015	1.000	1.014	.986
2002	1.122	1.099	1.021	1.015	1.006
2003	1.087	1.085	1.002	1.005	.997
2004	1.178	1.180	.998	.998	1.000
2005	1.059	1.062	.997	.992	1.005
2006	1.119	1.129	.991	.977	1.014
2007	1.115	1.090	1.023	1.003	1.020
2008	1.146	1.018	1.126	1.006	1.012
Geometric mean	**1.097**	**1.071**	**1.012**	**.999**	**1.004**
Panel B: DOM_BNKS					
1998	1.000	1.000	1.000	1.000	1.000
1999	1.093	.993	1.101	.986	1.007
2000	1.148	1.141	1.006	1.003	1.003
2001	1.032	1.001	1.030	1.033	.997
2002	1.139	1.112	1.024	1.031	.993
2003	1.057	.994	1.063	1.006	.988
2004	1.185	1.176	1.008	1.001	1.007
2005	1.072	1.070	1.002	.998	1.003
2006	1.102	1.150	.958	.960	.998
2007	1.085	1.094	.992	.990	1.002
2008	1.146	1.018	1.126	1.006	1.012
Geometric mean	**1.095**	**1.049**	**1.027**	**1.018**	**1.001**
Panel C: FOR_BNKS					
1998	1.000	1.000	1.000	1.000	1.000
1999	1.086	.972	1.118	.977	.995
2000	1.147	1.150	.997	1.000	.997
2001	1.001	1.026	.976	.998	.978
2002	1.108	1.088	1.018	1.002	1.016
2003	1.111	1.009	1.101	1.005	1.004
2004	1.173	1.184	.991	.996	.995
2005	1.048	1.055	.994	.988	1.006
2006	1.130	1.115	1.014	.988	1.026
2007	1.135	1.087	1.045	1.012	1.032
2008	1.137	1.020	1.115	1.005	1.014
Geometric mean	**1.096**	**1.053**	**1.041**	**.997**	**1.006**

Notes: The table presents the geometric mean of the bias-corrected bootstrap. Total factor productivity change (TFPCH) index and its mutually exhaustive components of technical change (TECHCH) and efficiency change (EFFCH) that is further decomposed into pure technical efficiency change (PEFFCH) and scale efficiency change (SECH), for all banks (ALL_BNKS) and different forms in the sample; Domestic Banks (DOM_BNKS) and Foreign Banks (FOR_BNKS).

4.2. Productivity of Malaysian banks: an analysis based on the number

Analysis based on productivity levels of banks may be biased by a few observations (Isik & Hassan, 2002). Therefore, it would be beneficial to perform analysis based on the number of banks, which is less sensitive to possible outliers. To address this concern, in the subsequent analysis, we elaborate further the productivity of Malaysian banks by summarizing the developments in the number of banks experiencing productivity progress or regress. The results are given in Panels A–C of Table 3. As the results in Panel A of Table 3 indicate, 26 (81.25%) banks have experienced productivity growth in 1999 before declining gradually to only 14 (63.64%) banks during the year 2008. It can also be observed from Panel A of Table 3 that the number of banks which experienced technological progress declined from 30 (93.75%) banks during the year 1999 to reach a low of 16 (72.73%) banks during the year 2008. Consequently, the number of banks which experienced technological regress increased from 2 (6.25%) banks during the year 1999 to 5 (22.73%) banks during the year 2008. It is also interesting to note that the number of Malaysian banks which have been efficient increased slightly from 5 (15.63%) banks in 1999 to 6 (27.27%) banks in 2008.

Panel B of Table 3 present the results of the analysis based on the number of domestic banks experiencing productivity progress and/or regress. As the results in Panel B of Table 4 indicate, 15 (78.95%) domestic banks have experienced productivity growth during the year 1999, before declining gradually to reach a low of 6 (66.67%) banks in 2008. Similarly, domestic banks which exhibit technological progress declined from 18 (94.74%) banks in 1999 to 7 (77.78%) banks in 2008. On the other hand, the number of domestic banks which have seen regress in their technology increased from 1 (5.26%) bank during the year 1999 to 2 (22.22%) banks in 2008. It is also apparent from Panel B of Table 4 that the number of domestic banks which experienced efficiency increase (decrease) declined (increased) from 3 (4) banks during the year 2000 to 2 (1) bank(s) during the year 2008.

The developments in the percentage change of the foreign banks productivity progress (regress) and efficiency increase (decrease) is discussed next. It is apparent that during the period under study the number of foreign banks which exhibit productivity progress (regress) declined (increased) from 11 (2) banks during the year 1999 to 8 (4) banks during the year 2008. On a similar note, the empirical findings seem to suggest that the number of foreign banks which experienced technological progress (regress) declined (increased) from 12 (1) bank(s) during the year 1999 to 9 (3) banks during the year 2008. Likewise, the number of foreign banks which experienced efficiency increase (decrease) increased (declined) from 2 (4) banks during year the year 2000 to 4 (2) banks in 2008.

Table 4 is constructed to examine the major sources of productivity progress (regress) and efficiency increase (decrease) in the Malaysian banking sector during the 1998–2008 period. The results given in Table 4 are simply a decomposition of Table 3. For instance, of those 21 banks that experienced productivity progress during the year 2000 as shown in Panel A of Table 4, the majority, 20 (83.33%), were the result of technological progress, while a (4.17%) bank's productivity progress were mainly attributed to efficiency increase. On the other hand, of the 3 banks, which experienced productivity regress during the year 2000, the majority, 2 (8.33%) banks, were the result of efficiency decline, while a (4.17%) bank's productivity regress was mainly due to technological regress. The results from Panel A in Table 4 indicates that of the 5 banks that experienced efficiency increase during the year 2000, 4 (16.67%) banks experienced the increase in efficiency attributed to the increase in scale efficiency while a (4.17%) bank experienced increase in pure technical efficiency. Also, from the 4 banks that experienced efficiency loss during the year 2000, 3 (12.50%) banks experienced the reduction in their efficiency mainly due to the decline in scale efficiency, whereas a (4.17%) bank faced the reduction mostly due to the decline in pure technical efficiency.

Panel B of Table 4 shows the results for the major source of productivity progress (regress) and efficiency increase (decrease) of the domestic banks. The results indicate that of the 9 domestic banks that experienced productivity progress during the year 2000, the majority, 8 (72.73%) banks,

Table 3. Developments in the number of Malaysian banks with productivity progress (regress) and efficiency increase (decrease)

Period	Productivity change (TFPCH)			Technological change (TECHCH)			Efficiency change (EFFCH)			Pure efficiency change (PEFFCH)			Scale efficiency change (SECH)		
	Progress # (%)	Regress # (%)	No Δ # (%)	Progress # (%)	Regress # (%)	No Δ # (%)	Increase # (%)	Decrease # (%)	No Δ # (%)	Increase # (%)	Decrease # (%)	No Δ # (%)	Increase # (%)	Decrease # (%)	No Δ # (%)
Panel A: ALL_BNKS															
1998–1999	26 (81.25)	6 (18.75)	0 (.00)	30 (93.75)	2 (6.25)	0 (.00)	5 (15.63)	8 (25.00)	19 (59.38)	3 (9.38)	7 (21.88)	22 (68.75)	8 (25.00)	5 (15.63)	19 (59.38)
1999–2000	21 (87.50)	3 (12.50)	0 (.00)	22 (91.67)	2 (8.33)	0 (.00)	5 (20.83)	4 (16.67)	15 (62.50)	1 (4.17)	2 (8.33)	21 (87.50)	5 (20.83)	4 (16.67)	15 (62.50)
2000–2001	13 (54.17)	11 (45.83)	0 (.00)	15 (62.50)	9 (37.50)	0 (.00)	4 (16.67)	7 (29.17)	13 (54.17)	2 (8.33)	1 (4.17)	21 (87.50)	4 (16.67)	7 (29.17)	13 (54.17)
2001–2002	20 (83.33)	4 (16.67)	0 (.00)	20 (83.33)	4 (16.67)	0 (.00)	7 (29.17)	3 (12.50)	14 (58.33)	4 (16.67)	1 (4.17)	19 (79.17)	6 (25.00)	4 (16.67)	14 (58.33)
2002–2003	17 (73.91)	6 (26.09)	0 (.00)	17 (73.91)	4 (17.39)	1 (4.35)	2 (8.70)	6 (26.09)	15 (65.22)	2 (8.70)	1 (4.35)	20 (86.96)	2 (8.70)	6 (26.09)	15 (65.22)
2003–2004	22 (95.65)	1 (4.35)	0 (.00)	22 (95.65)	1 (4.35)	0 (.00)	3 (13.04)	3 (13.04)	17 (73.91)	1 (4.35)	1 (4.35)	21 (91.30)	3 (13.04)	3 (13.04)	17 (73.91)
2004–2005	15 (65.22)	8 (34.78)	0 (.00)	17 (73.91)	6 (26.09)	0 (.00)	5 (21.74)	5 (21.74)	13 (56.52)	0 (.00)	4 (17.39)	19 (82.61)	6 (26.09)	4 (17.39)	13 (56.52)
2005–2006	19 (86.36)	3 (13.64)	0 (.00)	22 (100.00)	0 (.00)	0 (.00)	1 (4.55)	4 (18.18)	17 (77.27)	0 (.00)	4 (18.18)	18 (81.82)	2 (9.09)	3 (13.64)	17 (77.27)
2006–2007	19 (86.36)	3 (13.64)	0 (.00)	19 (86.36)	3 (13.64)	0 (.00)	4 (18.18)	2 (9.09)	16 (72.73)	1 (4.55)	1 (4.55)	20 (90.91)	3 (13.64)	2 (9.09)	17 (77.27)
2007–2008	14 (63.64)	7 (31.82)	1 (4.55)	16 (72.73)	5 (22.73)	1 (4.55)	6 (27.27)	3 (13.64)	13 (59.09)	3 (13.64)	2 (9.09)	17 (77.27)	6 (27.27)	3 (13.64)	13 (59.09)
Panel B: DOM_BNKS															
1998–1999	15 (78.95)	4 (21.05)	0 (.00)	18 (94.74)	1 (5.26)	0 (.00)	3 (15.79)	4 (21.05)	12 (63.16)	2 (10.53)	3 (15.79)	14 (73.68)	5 (26.32)	2 (10.53)	12 (63.16)
1999–2000	9 (81.82)	2 (18.18)	0 (.00)	9 (81.82)	2 (18.18)	0 (.00)	3 (27.27)	2 (18.18)	6 (54.55)	1 (9.09)	2 (18.18)	8 (72.73)	3 (27.27)	2 (18.18)	6 (54.55)
2000–2001	7 (63.64)	4 (36.36)	0 (.00)	7 (63.64)	4 (36.36)	0 (.00)	3 (27.27)	3 (27.27)	5 (45.45)	2 (18.18)	0 (.00)	9 (81.82)	3 (27.27)	3 (27.27)	5 (45.45)
2001–2002	10 (90.91)	1 (9.09)	0 (.00)	11 (100.00)	0 (.00)	0 (.00)	4 (36.36)	1 (9.09)	6 (54.55)	3 (27.27)	0 (.00)	8 (72.73)	3 (27.27)	2 (18.18)	6 (54.55)
2002–2003	7 (70.00)	3 (30.00)	0 (.00)	7 (70.00)	2 (20.00)	1 (10.00)	1 (10.00)	3 (30.00)	6 (60.00)	1 (10.00)	0 (.00)	9 (90.00)	1 (10.00)	3 (30.00)	6 (60.00)
2003–2004	9 (90.00)	1 (10.00)	0 (.00)	9 (90.00)	1 (10.00)	0 (.00)	3 (30.00)	1 (10.00)	6 (60.00)	1 (10.00)	0 (.00)	9 (90.00)	3 (30.00)	1 (10.00)	6 (60.00)
2004–2005	8 (80.00)	2 (20.00)	0 (.00)	8 (80.00)	2 (20.00)	0 (.00)	3 (30.00)	1 (10.00)	6 (60.00)	0 (.00)	1 (10.00)	9 (90.00)	3 (30.00)	1 (10.00)	6 (60.00)

(*Continued*)

Table 3. (*Continued*)

Period	Productivity change (TFPCH)			Technological change (TECHCH)			Efficiency change (EFFCH)			Pure efficiency change (PEFFCH)			Scale efficiency change (SECH)		
	Progress # (%)	Regress # (%)	No Δ # (%)	Progress # (%)	Regress # (%)	No Δ # (%)	Increase # (%)	Decrease # (%)	No Δ # (%)	Increase # (%)	Decrease # (%)	No Δ # (%)	Increase # (%)	Decrease # (%)	No Δ # (%)
2005–2006	7 (77.78)	2 (22.22)	0 (.00)	9 (100.00)	0 (.00)	0 (.00)	0 (.00)	2 (22.22)	7 (77.78)	0 (.00)	2 (22.22)	7 (77.78)	0 (.00)	2 (22.22)	7 (77.78)
2006–2007	8 (88.89)	1 (11.11)	0 (.00)	8 (88.89)	1 (11.11)	0 (.00)	1 (11.11)	2 (22.22)	6 (66.67)	0 (.00)	1 (11.11)	8 (88.89)	1 (11.11)	1 (11.11)	7 (77.78)
2007–2008	6 (66.67)	3 (33.33)	0 (.00)	7 (77.78)	2 (22.22)	0 (.00)	2 (22.22)	1 (11.11)	6 (66.67)	2 (22.22)	1 (11.11)	6 (66.67)	2 (22.22)	1 (11.11)	6 (66.67)
Panel C: FOR_BNKS															
1998–1999	11 (84.62)	2 (15.38)	0 (.00)	12 (92.31)	1 (7.69)	0 (.00)	2 (15.38)	4 (30.77)	7 (53.85)	1 (7.69)	4 (30.77)	8 (61.54)	3 (23.08)	3 (23.08)	7 (53.85)
1999–2000	12 (92.31)	1 (7.69)	0 (.00)	13 (100.00)	0 (.00)	0 (.00)	2 (15.38)	2 (15.38)	9 (69.23)	0 (.00)	0 (.00)	13 (100.00)	2 (15.38)	2 (15.38)	9 (69.23)
2000–2001	6 (46.15)	7 (53.85)	0 (.00)	8 (61.54)	5 (38.46)	0 (.00)	1 (7.69)	4 (30.77)	8 (61.54)	0 (.00)	1 (7.69)	12 (92.31)	1 (7.69)	4 (30.77)	8 (61.54)
2001–2002	10 (76.92)	3 (23.08)	0 (.00)	9 (69.23)	4 (30.77)	0 (.00)	3 (23.08)	2 (15.38)	8 (61.54)	1 (7.69)	1 (7.69)	11 (84.62)	3 (23.08)	2 (15.38)	8 (61.54)
2002–2003	10 (76.92)	3 (23.08)	0 (.00)	11 (84.62)	2 (15.38)	0 (.00)	1 (7.69)	3 (23.08)	9 (69.23)	1 (7.69)	1 (7.69)	11 (84.62)	1 (7.69)	3 (23.08)	9 (69.23)
2003–2004	13 (100.00)	0 (.00)	0 (.00)	13 (100.00)	0 (.00)	0 (.00)	0 (.00)	2 (15.38)	11 (84.62)	0 (.00)	1 (7.69)	12 (92.31)	0 (.00)	2 (15.38)	11 (84.62)
2004–2005	7 (53.85)	6 (46.15)	0 (.00)	9 (69.23)	4 (30.77)	0 (.00)	2 (15.38)	4 (30.77)	7 (53.85)	0 (.00)	3 (23.08)	10 (76.92)	3 (23.08)	3 (23.08)	7 (53.85)
2005–2006	12 (92.31)	1 (7.69)	0 (.00)	13 (100.00)	0 (.00)	0 (.00)	1 (7.69)	2 (15.38)	10 (76.92)	0 (.00)	2 (15.38)	11 (84.62)	2 (15.38)	1 (7.69)	10 (76.92)
2006–2007	11 (84.62)	2 (15.38)	0 (.00)	11 (84.62)	2 (15.38)	0 (.00)	3 (23.08)	0 (.00)	10 (76.92)	1 (7.69)	0 (.00)	12 (92.31)	2 (15.38)	1 (7.69)	10 (76.92)
2007–2008	8 (61.54)	4 (30.77)	1 (7.69)	9 (69.23)	3 (23.08)	1 (7.69)	4 (30.77)	2 (15.38)	7 (53.85)	1 (7.69)	1 (7.69)	11 (84.62)	4 (30.77)	2 (15.38)	7 (53.85)

Notes: Malaysian banks are categorized according to the following. Productivity growth: TFPCH > 1, Productivity loss: TFPCH < 1, Productivity stagnation: TFPCH = 1; Technological progress: TECHCH > 1, Technological regress: TECHCH < 1, Technological stagnation: TECHCH = 1; Efficiency, pure technical and scale increase: EFFCH, PEFFCH and SECH > 1, Efficiency, pure technical and scale decrease: EFFCH, PEFFCH and SECH < 1, No change in efficiency, pure technical and scale: EFFCH, PEFFCH and SECH = 1.

Table 4. Major Source of productivity progress (regress) and efficiency increase (decrease) in Malaysian banks

Period	Productivity progress mainly due to		Productivity regress mainly due to		No productivity Δ	Efficiency increase due to		Efficiency decrease due to		No efficiency Δ
	Efficiency increase # (%)	Technological progress # (%)	Efficiency decrease # (%)	Technological regress # (%)	# (%)	PEFFCH increase # (%)	SECH increase # (%)	PEFFCH decrease # (%)	SECH decrease # (%)	# (%)
Panel A: ALL_BNKS										
1998–1999	0 (.00)	26 (81.25)	5 (15.63)	1 (3.13)	0 (.00)	2 (6.25)	3 (9.38)	6 (18.75)	2 (6.25)	19 (59.38)
1999–2000	1 (4.17)	20 (83.33)	2 (8.33)	1 (4.17)	0 (.00)	1 (4.17)	4 (16.67)	1 (4.17)	3 (12.50)	15 (62.50)
2000–2001	3 (12.50)	10 (41.67)	3 (12.50)	8 (33.33)	0 (.00)	2 (8.33)	2 (8.33)	0 (.00)	7 (29.17)	13 (54.17)
2001–2002	3 (12.50)	17 (70.83)	2 (8.33)	2 (8.33)	0 (.00)	3 (12.50)	4 (16.67)	0 (.00)	3 (12.50)	14 (58.33)
2002–2003	1 (4.35)	16 (69.57)	2 (8.70)	4 (17.39)	0 (.00)	1 (4.35)	1 (4.35)	0 (.00)	6 (26.09)	15 (65.22)
2003–2004	0 (.00)	22 (95.65)	0 (.00)	1 (4.35)	0 (.00)	0 (.00)	3 (13.04)	1 (4.35)	2 (8.70)	17 (73.91)
2004–2005	1 (4.35)	14 (60.87)	3 (13.04)	5 (21.74)	0 (.00)	0 (.00)	5 (21.74)	1 (4.35)	4 (17.39)	13 (56.52)
2005–2006	1 (4.55)	18 (81.82)	3 (13.64)	0 (.00)	0 (.00)	0 (.00)	1 (4.55)	4 (18.18)	0 (.00)	17 (77.27)
2006–2007	2 (9.09)	17 (77.27)	0 (.00)	3 (13.64)	0 (.00)	1 (4.55)	3 (13.64)	1 (4.55)	1 (4.55)	16 (72.73)
2007–2008	1 (4.55)	13 (59.09)	2 (9.09)	5 (22.73)	1 (4.55)	3 (13.64)	3 (13.64)	1 (4.55)	2 (9.09)	13 (59.09)
Panel B: DOM_BNKS										
1998–1999	0 (.00)	15 (78.95)	3 (15.79)	1 (5.26)	0 (.00)	1 (5.26)	2 (10.53)	3 (15.79)	1 (5.26)	12 (63.16)
1999–2000	1 (9.09)	8 (72.73)	1 (9.09)	1 (9.09)	0 (.00)	1 (9.09)	2 (18.18)	1 (9.09)	1 (9.09)	6 (54.55)
2000–2001	3 (27.27)	4 (36.36)	1 (9.09)	3 (27.27)	0 (.00)	2 (18.18)	1 (9.09)	0 (.00)	3 (27.27)	5 (45.45)
2001–2002	1 (9.09)	9 (81.82)	1 (9.09)	0 (.00)	0 (.00)	3 (27.27)	1 (9.09)	0 (.00)	1 (9.09)	6 (54.55)
2002–2003	0 (.00)	7 (70.00)	1 (10.00)	2 (20.00)	0 (.00)	1 (10.00)	0 (.00)	0 (.00)	3 (30.00)	6 (60.00)
2003–2004	0 (.00)	9 (90.00)	0 (.00)	1 (10.00)	0 (.00)	0 (.00)	3 (30.00)	0 (.00)	1 (10.00)	6 (60.00)
2004–2005	0 (.00)	8 (80.00)	0 (.00)	2 (20.00)	0 (.00)	0 (.00)	3 (30.00)	0 (.00)	1 (10.00)	6 (60.00)
2005–2006	0 (.00)	7 (77.78)	2 (22.22)	0 (.00)	0 (.00)	0 (.00)	0 (.00)	2 (22.22)	0 (.00)	7 (77.78)
2006–2007	0 (.00)	8 (88.89)	0 (.00)	1 (11.11)	0 (.00)	0 (.00)	1 (11.11)	1 (11.11)	1 (11.11)	6 (66.67)
2007–2008	1 (11.11)	5 (55.56)	1 (11.11)	2 (22.22)	0 (.00)	2 (22.22)	0 (.00)	1 (11.11)	0 (.00)	6 (66.67)

(*Continued*)

Table 4. (*Continued*)

Period	Productivity progress mainly due to		Productivity regress mainly due to		No productivity Δ	Efficiency increase due to		Efficiency decrease due to		No efficiency Δ
	Efficiency increase # (%)	Technological progress # (%)	Efficiency decrease # (%)	Technological regress # (%)	# (%)	PEFFCH increase # (%)	SECH increase # (%)	PEFFCH decrease # (%)	SECH decrease # (%)	# (%)
Panel C: FOR_BNKS										
1998–1999	0 (.00)	11 (84.62)	2 (15.38)	0 (.00)	0 (.00)	1 (7.69)	1 (7.69)	3 (23.08)	1 (7.69)	7 (53.85)
1999–2000	0 (.00)	12 (92.31)	1 (7.69)	0 (.00)	0 (.00)	0 (.00)	2 (15.38)	0 (.00)	2 (15.38)	9 (69.23)
2000–2001	0 (.00)	6 (46.15)	2 (15.38)	5 (38.46)	0 (.00)	0 (.00)	1 (7.69)	0 (.00)	4 (30.77)	8 (61.54)
2001–2002	2 (15.38)	8 (61.54)	1 (7.69)	2 (15.38)	0 (.00)	0 (.00)	3 (23.08)	0 (.00)	2 (15.38)	8 (61.54)
2002–2003	1 (7.69)	9 (69.23)	1 (7.69)	2 (15.38)	0 (.00)	0 (.00)	1 (7.69)	0 (.00)	3 (23.08)	9 (69.23)
2003–2004	0 (.00)	13 (100.00)	0 (.00)	0 (.00)	0 (.00)	0 (.00)	0 (.00)	1 (7.69)	1 (7.69)	11 (84.62)
2004–2005	1 (7.69)	6 (46.15)	3 (23.08)	3 (23.08)	0 (.00)	0 (.00)	2 (15.38)	1 (7.69)	3 (23.08)	7 (53.85)
2005–2006	1 (7.69)	11 (84.62)	1 (7.69)	0 (.00)	0 (.00)	0 (.00)	1 (7.69)	2 (15.38)	0 (.00)	10 (76.92)
2006–2007	2 (15.38)	9 (69.23)	0 (.00)	2 (15.38)	0 (.00)	1 (7.69)	2 (15.38)	0 (.00)	0 (.00)	10 (76.92)
2007–2008	0 (.00)	8 (61.54)	1 (7.69)	3 (23.08)	1 (7.69)	1 (7.69)	3 (23.08)	0 (.00)	2 (15.38)	7 (53.85)

Notes: Malaysian banks are categorized according to the following. (1) Productivity progress: TFPCH > 1, (2) Productivity regress: TFPCH < 1, (3) Productivity stagnation: TFPCH = 1. (1) Technological progress: TECHCH > 1, (2) Technological regress: TECHCH < 1, (3) Technological stagnation: TECHCH = 1. (1) Efficiency, pure technical and scale increase: EFFCH, PEFFCH and SECH > 1, (2) Efficiency, pure technical and scale decrease: EFFCH, PEFFCH and SECH < 1, (3) No change in efficiency, pure technical and scale: EFFCH, PEFFCH and SECH = 1.

were the result of technological progress, while only a (9.09%) bank productivity progress was mainly attributed to efficiency increase. On the other hand, of the 2 domestic banks, which experienced productivity regress during the year 2000, a (9.09%) bank experienced the regress due to efficiency decrease, while a (9.09%) bank's productivity regress was due to technological regress. The results from Panel B in Table 4 indicates that of the 3 domestic banks that experienced efficiency increase during the year 2000, 2 (18.18%) banks experienced the increase in efficiency attributed to the increase in scale efficiency, while a (9.09%) bank experienced increase in pure technical efficiency. In addition, from the 2 banks that experienced efficiency loss during the year 2000, a (9.09%) bank experienced the decline due to the decline in pure technical efficiency, while a (9.09%) bank's efficiency decline was mainly due to scale efficiency.

Panel C of Table 4 exhibits the results for the major source of productivity progress (regress) and efficiency increase (decrease) of the foreign banks. The results indicate that productivity progress of the 12 (92.31%) foreign banks during the year 2000 was mainly attributed to technological progress. On the other hand, a (7.69%) foreign bank experienced productivity regress during the year 2000 due to efficiency decline. The results from Panel C in Table 4 indicate that of the 2 (15.38%) foreign banks that experienced efficiency increase during the year 2000, both banks experienced the increase attributed to scale efficiency. On the other hand, both foreign banks that experienced efficiency loss during the year 2000 were the result of scale efficiency decline.

4.3. Productivity of the domestic relative to the foreign banks
Like the earlier studies, we have so far assumed that the domestic and foreign banks came from the same legal and business environment. However, it may be questionable to pool the domestic and foreign banks into a common frontier. Therefore, in the next step, we test whether there is significant difference between the foreign and domestic banks' technology. Foreign banks have entered the Malaysian banking sector by establishing a branch. Foreign subsidiaries have their own sets of books i.e. they are distinct organizations from their parents. Foreign banks may also have quite different goals from their domestic bank peers, as they may be inclined to trade-off between productivity and market share to penetrate a local market (Isik & Hassan, 2002).

Furthermore, lack of exposure in a lesser-known market may manifest itself in the form of extra information gathering costs for clients. The foreign owned banks may also be at disadvantage in terms of input efficiency, driven primarily by excess expenditures on personnel, or over reliance on purchased funds in the inter-bank market, which is costlier. Alternatively, foreign banks may possess some distinct advantages, stemming from their asset portfolios. Relative to their domestic bank counterparts, foreign banks' asset portfolios are skewed towards investment securities, of which the administrative and transactional costs are relatively lower than loans.

Following the procedures outlined in Aly, Grabowski, Pasurka, and Rangan (1990), Elyasiani and Mehdian (1992), and Isik and Hassan (2002) among others, we employ a battery of parametric (*t*-test) and non-parametric (Kolmogorov–Smirnov and Mann–Whitney [Wilcoxon Rank-Sum]) tests to test the null hypothesis of identical frontiers between the foreign and domestic banks' efficiency and productivity. The results are presented in Table 5. The results seem to suggest that the foreign owned banks have been slightly more productive (1.117 > 1.114) compared to their domestic owned bank counterparts, attributed to a higher EFFCH (1.006 > 1.004) and greater technological progress (1.109 > 1.108). However, we do not find statistically significant difference in the mean between the foreign and domestic owned banks efficiency and productivity. The *t*-test results are further confirmed by the results derived from the non-parametric Mann–Whitney [Wilcoxon Rank-Sum] and Kolmogorov–Smirnov tests. We therefore conclude that there is no statistically significant difference between the efficiency and productivity of the foreign owned compared to the domestic owned banks.

Based on the results, we failed to reject the null hypothesis at the 5% levels of significance that the foreign owned and domestic owned banks are drawn from the same population and have

Table 5. Summary of parametric and non-parametric tests

	Test groups				
	Parametric test		Non-parametric tests		
Individual tests	*t*-Test		Mann–Whitney [Wilcoxon Rank-Sum] test		Kolmogorov–Smirnov [K–S] test
Test statistics	*t* (Prb > *t*)		*z* (Prb > *z*)		$\text{Distribution}_{DB} = \text{Distribution}_{FB}$
	Mean	*t*	Mean rank	*z*	K–S (Prb > K–S)
Efficiency change (EFFCH)					
Domestic Banks	1.004	−.138	123.44	−.066	.443
Foreign Banks	1.006		117.12		
Technological change (TECHCH)					
Domestic Banks	1.108		118.43		
Foreign Banks	1.109		121.32		
		−.206		−.817	.595
Pure technical efficiency change (PEFFCH)					
Domestic Banks	1.003	−.022	124.89	−.322	.598
Foreign Banks	.998		116.90		
Scale efficiency change (SECH)					
Domestic Banks	1.001	.875	123.53	−1.526	.611
Foreign Banks	1.008		117.04		
Productivity change (TFPCH)					
Domestic Banks	1.114	−.931	119.68	−.841	.467
Foreign Banks	1.117		120.27		

Notes: Test methodology follows among others, Aly et al. (1990), Elyasiani and Mehdian (1992), and Isik and Hassan (2002). Parametric (*t*-test) and non-parametric (Mann–Whitney and Kolmogorov–Smirnov) tests test the null hypothesis of equal mean between the two models.

identical technologies. The results imply that there is no significant difference between the foreign owned and domestic owned banks' technologies (frontiers) and that it is appropriate to construct a combined frontier. Furthermore, the results from the Levene's test for equality of variances do not reject the null hypothesis that the variances among the foreign owned and domestic owned banks are equal, implying that we can assume the variances among the foreign and domestic banks are equal. Our findings corroborate with the findings by among others, Isik and Hassan (2002).

5. Concluding remarks and directions for future research

The present study employs the non-parametric MPI method to examine the evolution of Malaysian banking sector's efficiency and productivity during the period of 1998–2008. The preferred methodology enables us to isolate efforts to catch up to the frontier (efficiency change) from shifts in the frontier (TECHCH). The empirical findings suggest that the Malaysian banking sector has exhibited a marginal productivity progress attributed to the increase in efficiency change. The decomposition of the scale efficiency into its mutually exhaustive pure technical and scale efficiency components show that scale efficiency has largely contributed to the favorable increase in the Malaysian banking sector's efficiency levels.

We have also examined the major sources of productivity progress/regress of the domestic and foreign banks operating in the Malaysian banking sector. The empirical findings from this study suggest that the domestic banks have exhibited a marginal productivity increase attributed to the increase in EFFCH. On the other hand, we find that regress in TECHCH outweighs the increase in efficiency of the foreign banks and consequently has had adverse impacts on the foreign banks' TFP levels.

The empirical findings from this study have considerable policy relevance. First, in view of the increasing competition resulting from the more liberalized environment, the continued success of the Malaysian banking sector depends on its efficiency and productivity. Therefore, bank managements as well as the policy-makers will be more inclined to find ways to obtain the optimal utilization of capacities as well as making the best use of their resources, so that these resources are not wasted during the production of banking products and services. Moving forward it is reasonable to expect that the policy direction to be directed towards enhancing the efficiency and productivity of banks operating in the Malaysian banking sector with the aim of intensifying the robustness and stability of the financial system.

Secondly, most of Malaysian banks are small by global standards. Within the context of the Malaysian banking sector, the earlier studies have found that the small financial institutions are at disadvantage in terms of technological advancements compared to their large counterparts (e.g. Sufian, 2008). It would be reasonable to expect that the large banks could have better capability to invest in the state of the art technologies. To this end, the role of technology advancement is particularly important given that banks with relatively more advanced technologies may have added advantage compared to their peers. Furthermore, investments in technology has important ramifications since it could help to both reduce the negative effect of macroeconomic shocks and to use its changes to acquire (or retain) competitive advantage. In this regard, consolidation among the small banking institutions may help them to better withstand macroeconomic shocks like the Asian financial crisis. Moreover, from the economies of scale perspectives, consolidation among the small banking institutions could facilitate them to better reap the benefits of economies of scale.

Due to its limitations, the paper could be extended in a variety of ways. Firstly, the scope of this study could be further extended to investigate changes in cost, allocative, and technical efficiencies over time by employing the DEA method. Secondly, future research into the efficiency and productivity of Malaysian banks could also consider the production function along with the intermediation function. Finally, the non-parametric frontier analysis used in this paper could be combined with the stochastic frontier analysis method of estimating the frontier. This should testify to the robustness of the results against alternative functions and estimation methods.

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Notes

1. The MPI was not invented by Malmquist. In his paper, (Malmquist, 1953) brought input functions of distance into an analysis of consumption, developing a method for the empirical measurement of standard of living. The change in living standards is defined as the ratio of two input functions of distance. Before the Malmquist paper, the input function of distance was brought into a paper by Debreu (1951), while the output function of distance was first introduced by Shephard in his book (1953). The natural development of their papers was the definition of the index of change of TFP as the ratio of two input or output functions of distance. Some 31 years had to pass before it arrived. The Malmquist index of change in TFP was proposed in a paper for the first time in Caves, Christensen, and Diewert (1982).

2. See Simar and Wilson (2000) for a thorough analysis based on Monte Carlo evidence.
3. This method is founded on the idea of "reflecting" the probability mass lying beyond unity where, in theory, no probability mass should exist.
4. Tables A1–A3 in Appendix contains the detailed results for the bias-corrected TFPCH, TECHCH, and EFFCH indices, respectively, for all banks for the year 2008. To maintain brevity, we do not report the detailed results for all banks during all years in the paper, but are available upon request from the authors.

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Appendix

Table A1. The bias corrected TFPCH index

Bank	Original TFPCH	Bias corrected TFPCH	90% Confidence interval		95% Confidence interval		99% Confidence interval	
			Lower bound	Upper bound	Lower bound	Upper bound	Lower bound	Upper bound
Domestic Banks								
Affin Bank	1.024	1.196***	1.184	1.219	1.175	1.223	1.168	1.229
Alliance Bank	.947	1.298***	1.293	1.301	1.273	1.302	1.268	1.304
Arab-Malaysian Bank	1.082	.960***	.942	.971	.940	.973	.936	.977
CIMB Bank	1.106	1.279***	1.273	1.289	1.268	1.290	1.263	1.295
EON Bank	.993	.919***	.917	.929	.916	.932	.915	.936
Hong Leong Bank	.972	1.245***	1.242	1.248	1.238	1.259	1.237	1.265
Maybank	1.044	.964***	.960	.969	.959	.971	.957	.974
Public Bank	.970	1.349***	1.341	1.361	1.336	1.363	1.331	1.368
RHB Bank	1.097	1.348***	1.312	1.360	1.305	1.362	1.290	1.365
Foreign Banks								
ABN-AMRO Bank	4.218	1.173***	1.164	1.179	1.158	1.181	1.155	1.184
Bangkok Bank	1.208	1.411***	1.409	1.412	1.409	1.413	1.408	1.414
Bank of America	1.113	.936***	.934	.943	.932	.947	.931	.954
Bank of China	1.226	1.057***	1.046	1.066	1.043	1.070	1.039	1.075
Bank of Nova Scotia	1.664	1.323***	1.322	1.327	1.321	1.327	1.321	1.328
Bank of Tokyo	1.013	1.299***	1.283	1.303	1.283	1.304	1.283	1.304
Citibank	1.436	.936***	.930	.939	.929	.940	.927	.942
Deutsche Bank	1.752	1.440***	1.436	1.440	1.434	1.440	1.434	1.441
Hongkong Bank	1.072	.994***	.980	1.014	.978	1.017	.976	1.023
JP Morgan Chase	1.656	1.363***	1.358	1.367	1.356	1.369	1.353	1.370
OCBC Bank	.998	.944***	.942	.946	.941	.947	.941	.948
Standard Chartered Bank	1.506	1.000***	.998	1.009	.997	1.009	.996	1.009
UOB Bank	.865	1.089***	1.075	1.108	1.069	1.114	1.063	1.122

Notes: The table contains the original and bias-corrected results of the TFPCH index for the year 2008. The results show that at the 99% confidence interval, six domestic banks' TFPCH is biased on the downside, while for the other three domestic banks, the TFPCH scores are biased on the upside. On the other hand, the results for the foreign banks indicate that in 10 cases the estimated TFPCH scores for the foreign banks are biased on the upside, while in three other cases the estimated TFPCH scores are biased on the downside (statistically significant at the 1% level in all cases).

For the purpose of brevity, we do not present the complete results for all years, but are available upon request from the authors.

***Significant bias at the 99% confidence interval.

Table A2. The bias corrected TECHCH index

Bank	Original TECHCH	Bias corrected TECHCH	90% Confidence interval		95% Confidence interval		99% Confidence interval	
			Lower bound	Upper bound	Lower bound	Upper bound	Lower bound	Upper bound
Domestic Banks								
Affin Bank	1.349	1.196***	1.130	1.241	1.120	1.308	1.101	1.332
Alliance Bank	1.367	1.160***	1.095	1.231	1.084	1.264	1.060	1.291
Arab-Malaysian Bank	1.494	.960***	.931	.980	.919	.984	.899	.992
CIMB Bank	1.424	1.279***	1.239	1.338	1.222	1.408	1.183	1.429
EON Bank	1.379	1.045***	.947	1.065	.917	1.072	.891	1.084
Hong Leong Bank	1.311	1.245***	1.140	1.290	1.109	1.364	1.082	1.383
Maybank	1.290	.964***	.884	1.009	.854	1.078	.819	1.097
Public Bank	1.310	1.349	1.237	1.430	1.195	1.495	1.149	1.524
RHB Bank	1.174	1.158	1.102	1.202	1.090	1.224	1.071	1.253
Foreign Banks								
ABN-AMRO Bank	2.041	1.173***	1.073	1.221	1.043	1.283	1.014	1.313
Bangkok Bank	1.353	1.250***	1.195	1.264	1.181	1.269	1.164	1.282
Bank of America	1.315	.936***	.850	.948	.823	.952	.798	.960
Bank of China	1.527	1.057***	.961	1.094	.931	1.111	.901	1.138
Bank of Nova Scotia	1.664	1.227***	1.146	1.247	1.133	1.252	1.112	1.262
Bank of Tokyo	1.013	1.161***	1.075	1.210	1.062	1.227	1.045	1.264
Citibank	1.554	1.019***	.970	1.033	.962	1.039	.944	1.049
Deutsche Bank	1.752	1.351***	1.260	1.404	1.247	1.426	1.212	1.451
Hongkong Bank	1.343	.994***	.913	1.018	.886	1.025	.847	1.046
JP Morgan Chase	1.656	1.363***	1.268	1.419	1.251	1.511	1.214	1.538
OCBC Bank	1.379	.944***	.859	.983	.828	1.045	.796	1.076
Standard Chartered Bank	1.521	1.000***	.935	1.047	.922	1.099	.891	1.113
UOB Bank	1.337	1.128***	1.039	1.154	1.020	1.161	.996	1.174

Notes: The table shows the original and bias-corrected results of the TECHCH index for the year 2008. The results show that in seven cases the estimated TECHCH scores for the domestic banks are biased on the downside (statistically significant at the 1% level in all cases). Likewise, the results for the foreign banks indicate that in 12 cases the estimated TECHCH scores are biased on the downside, while in one case the estimated TECHCH scores are biased on the upside (statistically significant at the 1% level in all cases).

For the purpose of brevity, we do not present the complete results for all years, but are available upon request from the authors.

***Significant bias at the 99% confidence interval.

Table A3. The bias corrected EFFCH index

Bank	Original EFFCH	Bias corrected EFFCH	90% Confidence interval		95% Confidence interval		99% Confidence interval	
			Lower bound	Upper bound	Lower bound	Upper bound	Lower bound	Upper bound
Domestic Banks								
Affin Bank	.759	1.000***	.956	1.072	.880	1.080	.847	1.092
Alliance Bank	.693	1.119***	1.034	1.178	.985	1.189	.953	1.207
Arab-Malaysian Bank	.724	1.000***	.971	1.030	.966	1.037	.958	1.058
CIMB Bank	.776	1.000***	.951	1.036	.879	1.047	.853	1.076
EON Bank	.720	.880***	.864	.959	.859	.982	.849	1.001
Hong Leong Bank	.742	1.000***	.961	1.081	.888	1.107	.869	1.127
Maybank	.809	1.000***	.951	1.081	.864	1.110	.836	1.138
Public Bank	.740	1.000***	.933	1.084	.869	1.112	.836	1.136
RHB Bank	.934	1.164***	1.094	1.209	1.060	1.216	1.028	1.232
Foreign Banks								
ABN-AMRO Bank	2.066	1.000***	.953	1.082	.882	1.105	.846	1.126
Bangkok Bank	.893	1.128***	1.116	1.177	1.111	1.188	1.098	1.202
Bank of America	.846	1.000***	.986	1.091	.982	1.119	.972	1.144
Bank of China	.803	1.000***	.955	1.091	.931	1.117	.902	1.141
Bank of Nova Scotia	1.000	1.079***	1.061	1.145	1.057	1.154	1.047	1.171
Bank of Tokyo	1.000	1.119**	1.060	1.196	1.037	1.208	.995	1.221
Citibank	.924	.918	.904	.960	.898	.968	.889	.984
Deutsche Bank	1.000	1.065*	1.021	1.132	1.000	1.142	.977	1.164
Hongkong Bank	.798	1.000***	.969	1.083	.962	1.112	.945	1.146
JP Morgan Chase	1.000	1.000	.955	1.068	.871	1.079	.846	1.101
OCBC Bank	.724	1.000***	.956	1.085	.880	1.111	.835	1.139
Standard Chartered Bank	.990	1.000	.951	1.069	.890	1.079	.873	1.107
UOB Bank	.647	.966***	.936	1.051	.929	1.070	.913	1.087

Notes: The table shows the original and bias-corrected results of the EFFCH index for the year 2008. The results show that in all nine cases the estimated EFFCH scores for the domestic banks are biased on the upside (statistically significant at the 1% level in all cases). On the other hand, the results for the foreign banks indicate that in three cases the estimated EFFCH scores are biased on the downside, while in seven other cases the estimated EFFCH scores are biased on the upside (statistically significant at the 10% level or better).

For the purpose of brevity, we do not present the complete results for all years, but are available upon request from the authors.

*Significant bias at the 90% confidence interval.

**Significant bias at the 95% confidence interval.

***Significant bias at the 99% confidence interval.