Technical efficiency of Islamic and conventional banks: Evidence from the stochastic meta-frontier directional distance function approach

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Abstract

We employ the stochastic meta-frontier directional distance function (SMF-DDF) approach to examine technical inefficiency of Islamic and conventional banks in 28 countries with specific attention to the role of Shariah supervisory board (SSB)—an additional layer of governance in Islamic banks. Islamic banks have lower group-specific inefficiency but higher meta-inefficiency compared to their conventional counterparts, which is driven by Islamic banks' failure to adopt the best available banking technology. The SSB is found to be conducive in reducing technical inefficiency of Islamic banks.

Key words: Stochastic meta-frontier, Directional distance function, Islamic banking, Efficiency, Shariah supervisory board.

JEL classification: D24, G21, G28, G34

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1. Introduction

In recent years, Islamic banks' technical efficiency has received considerable attention as a result of rapid growth of the Islamic banking industry across countries (Abdul-Majid et al., 2010; Mobarek and Kalonov, 2014; Johnes et al., 2014; Rosman et al., 2014; Belanès et al., 2015; Batir et al., 2017). Previous studies provide mixed findings with some providing evidence of higher technical efficiency in Islamic banks compared to conventional banks (Ahmad and Luo, 2011; Hassan and Abdul-Majid, 2011; Batir et al., 2017), while others providing evidence of lower or similar technical efficiency in Islamic banks (Abdul-Majid et al., 2010; Mobarek and Kalonov, 2014; Johnes et al., 2014; Wanke et al., 2016a). Furthermore, to estimate technical efficiency of two heterogeneous bank groups, the extant literature generally uses a common efficiency frontier based on the data envelopment analysis (DEA) with Shephard's (1970) input or output distance function.[1] In addition, previous studies overlook banks' regular board governance and Islamic banks' Shariah supervisory board (SSB) governance as drivers of technical efficiency. The SSB is an additional layer of governance in Islamic banks with the role to ensure adherence to Islamic principles in acquiring inputs and transforming inputs into outputs. Hence, SSB attributes are relevant to Islamic banks' technical efficiency. Our study is motivated by above gaps in the literature, and presents the following novelties in the context of technical efficiency of Islamic vis-à-vis conventional banks.

First, prior studies have estimated technical inefficiency of Islamic banks and their conventional counterparts by employing either Shephard's (1970) input distance function (Mobarek and Kalonov, 2014; Johnes et al., 2014; Sufian et al., 2009; Rosman et al., 2014; Belanès et al., 2015) or output distance function (Abdul-Majid et al., 2010; Hassan and Abdul-Majid, 2011). Unlike our predecessors, we estimate inefficiency using the directional distance

[1] Only two studies (Abdul-Majd et al., 2010; Mobarek and Kalonov, 2014) use stochastic frontier analysis to estimate Islamic banks' technical efficiency under a common frontier but the use of stochastic meta-frontier directional distance function (SMF-DDF) approach was beyond the scope of their study.

function (DDF) of Chambers et al. (1998). The DDF has not been previously used to estimate technical inefficiency of Islamic and conventional banks. While Shephard's (1970) distance function measures technical inefficiency either in the input direction or output direction, the DDF measures how much outputs can be expanded and inputs can be contracted concurrently to enable banks to operate on the efficient frontier. The DDF is also flexible in terms of functional form, as it specifies quadratic function, which unlike its translog counterpart allows use of observations with non-positive values and provides better approximation properties (Färe et al., 2010).

Second, previous studies have typically estimated Islamic and conventional banks' technical inefficiency employing a common efficient frontier, which presumes that both bank groups have access to the same production technology. Johnes et al.'s (2014) study is an exception that relaxes this assumption using a DEA meta-frontier model of efficiency proposed by Charnes et al. (1981). In contrast to a common frontier, a meta-frontier takes into account differences in efficiency frontiers across firm groups (Bos and Schmiedel, 2007). Our paper contributes to this strand of literature by employing a stochastic meta-frontier (SMF) framework of Huang et al. (2014) as opposed to the DEA meta-frontier that was employed by Charnes et al. (1981), Battese et al. (2004) and O'Donnell et al. (2008). The advantage of the SMF approach is that it allows us to employ stochastic frontier analysis (SFA) in estimating both group-specific inefficiency as well as meta-inefficiency. Consequently, it enables drawing inferences about model parameters, group-specific inefficiency, technology gap (TG), and the determinants of group-specific inefficiency and TG (for details see Huang et al., 2014, 2015).[2]

Third, we investigate the effects of regular board governance as well as SSB governance on technical efficiency. Previous studies largely examine the effect of regular board governance

[2] Huang et al. (2015) use the stochastic meta-frontier directional distance function (SMF-DDF) to estimate technical inefficiency of banks in Central and Eastern European countries. We employ this approach to estimate technical inefficiency of Islamic vis-a-vis conventional banks in 28 countries.

on performance of conventional banks (Grove et al., 2011; Pathan and Faff, 2013; Liang et al., 2013; Salim et al., 2016; Wang et al., 2012). Mollah and Zaman (2015) extend this line of research by examining the effects of both SSB and regular board governance on performance (accounting-based measures) of conventional and Islamic banks. None of the previous studies examines neither the effect of regular board governance nor the effect of SSB governance on Islamic banks' technical efficiency. Our study fills these research gaps, which are further elaborated in Table A1 in the Appendix.[3]

We use a matched sample of 188 Islamic and conventional banks from 28 countries over the period 2003-2014. The results show that Islamic banks have lower group-specific technical inefficiency than conventional banks but they lack the adoption of the best technology available to the entire banking industry. Consequently, compared to conventional banks, Islamic banks have higher meta-inefficiency that captures the joint effects of group-specific inefficiency and technology gap. Good SSB governance reduces technical inefficiency in Islamic banks. In contrast, good regular board governance is accompanied by higher technical inefficiency for both bank groups. The key message of our paper is that Islamic banks can reduce their technical inefficiency by strengthening Shariah supervisory board governance and catching up with their conventional peers in terms of advanced technologies.

The rest of the paper unfolds as follows. Section 2 describes the relevant hypotheses. Section 3 presents data and summary statistics of variables. Section 4 provides the DDF and stochastic meta-frontier frameworks for modelling inefficiency, and the corresponding results. In Sections 5 and 6, we present the determinants of technical inefficiency and additional test results, respectively. Section 7 concludes the paper.

[3] An examination of technical inefficiency based on the SMF-DDF framework was beyond the scope of previous studies on Islamic banks. Furthermore, prior research does not examine the effects of SSB and regular board governance on Islamic banks' technical inefficiency.

2. Hypothesis development

Islamic banks' adherence to the Shariah principles for banking business differentiate them from their conventional counterparts in terms of choices of inputs and outputs, and the production process. This in turn may lead to divergence in technical inefficiency between the two bank groups. Furthermore, conventional banks are led by a regular board of directors, while Islamic banks have an additional layer of governance—SSB governance. Thus, we put forward hypotheses pertaining to inefficiency differential between the two bank groups and the role of dual-board governance mechanism in influencing technical inefficiency of Islamic banks.

2.1 Are Islamic banks more or less technically efficient than conventional banks?

Islamic banks provide financial intermediation services similar to conventional banks but unlike conventional banks, they adhere to Shariah principles in providing such services. The provision of Shariah compliant banking products and services may influence their ability to maximize output for a given input-mix. For instance, the Shariah impermissibility on interest-based transactions and investment in a number of business sectors (e.g. tobacco, alcohol, gambling, and defense products) may constrain Islamic banks in reaching potential output from any given input-mix. Furthermore, the Shariah principles require Islamic banks to back all transactions by real economic contracts with tangible assets (Hasan and Dridi, 2010; Beck et al., 2013), which can be an impediment to attaining maximum feasible output from a given input-mix.

The Shariah restrictions on trading of interest-bearing financial instruments and derivative products may limit Islamic banks' use of some modern banking technologies and innovative products to enhance technical efficiency (Abdul-Majid et al., 2010). Islamic banks may also need to devote considerable human capital to produce Shariah compliant financial products (Johnes et al., 2014), imposing an additional constraint in gaining efficiency. A conventional bank, on the other hand, can duplicate production process of the best-performing banks regardless of those banks' religious orientation. Furthermore, Islamic banks may face comparative disadvantage in achieving economies of scale due to their smaller customer base compared to their conventional counterparts.[4] In the light of the above arguments, we therefore propose the following hypothesis:

H_1: Islamic banks are more technical inefficient than conventional banks.

2.2 Does corporate governance influence technical efficiency of banks?

2.2.1 Regular board governnace and technical efficiency

Better board governance can increase technical efficiency of banks by an effective oversight of managers' opportunistic decision-making regarding the choices of inputs, outputs and production technologies (Dong et al., 2017). Also, the advisory ability and the networking connections of a strong board may help banks in inproving efficiency by bringing product and managerial innovations (Hillman and Dalziel, 2003; Balsmeier et al., 2017).

However, bank managers may be reluctant to seek advice from a strong board to avoid intensive scrutiny and the interference of board in decision-making (Adams and Ferreira, 2007). In a better-governed bank, managers may be too cautious to adopt innovative production technologies due to the greater threat of being fired or punished for adverse outcomes of unproven technology (Jensen, 1986). Thus better board governance can reduce technicaly efficiency. Furthermore, shareholder-friendly board may restrain bank managers from adopting innovative banking technologies to achive higher technical efficiency in the long-term at the cost of short-term shareholder wealth maximization (Balsmeier et al., 2017). This may also

[4] Islamic banking system co-exist with conventional banking system in 31 countries but it accounts for less than 15% of total domestic banking assets in 20 countries (IFSB, 2016).

reduce technical efficiency of banks. Altogether, better board governance have potential to either increase or decrease bank efficiency. Therefore, the following hypotheis is proposed:

H_{2a}: Board governance affects technical efficiency.

2.2.2 Shariah supervisory board (SSB) governance and Islamic banks' technical efficiency

The primary distinguishing feature of Islamic banks' corporate governance framework is the presence of the SSB as a complementary governance mechanism to the regular board of directors (Abdelsalam et al., 2016). The SSB monitors and advise Islamic banks' managers to ensure Islamic banks' compliance with Shariah principles. From the perspective of agency theory (Jensen and Meckling, 1976), a negative effect of SSB governance on technical inefficiency is expected as better SSB governance may strengthen monitoring of managers, leading to a reduction of opportunistic usage of resources and suboptimal input-output combination. The stronger Shariah control can also results in conservative financing and lending decisions as Shariah prohibits excessive risk-taking (*gharar*), which in turn may decrease deviation of actual output from potential output.

In addition to its monitoring role, the integrative Shariah guidence of SSB to bank managers enables to bridge the knowledge gap between modern finance and Shariah, which can reinforce technical efficiency by making the entire production process of Islamic banks (e.g. developemnt of Shariah compliant fianncial products, SSB approval, and implementation of business decisions) faster. The SSB as a provider of resources (e.g. legitimacy, networking) to manager can enhance customer confidence about an Islamic bank's Shariah compliance. This may increase customer base of an Islamic bank, relaxing input supply constraints and helping it to reach its potential outputs. Considering all these factors, we propose the following hypotheis:

H_{2b}: Shariah supervision of Islamic banks reduces technical inefficiency.

3. Data and summary statistics of variables

3.1 Data

We use a sample of 94 Islamic and 94 conventional banks from 28 countries with a dual-banking system. To construct the sample, fully-fledged Islamic banks are selected first from 28 countries[5] and then using average bank size, as measured by total assets, they are matched with their conventional counterparts to mitigate sample selection bias (Berger et al., 2014). This approach results in a matched sample of total 188 banks (see Table 1). The sample covers the period 2003–2014, where the starting year is chosen to avoid potential structural breaks in data due to the 2002 Sarbanes-Oxley Act. The financial data (e.g. output quantities, inputs, quasi fixed-input and total assets) are obtained from the Bankscope database. The data for SSB regular board governance and bank age are hand-collected from the annual reports published on the websites of the respective banks. The banking industry-specific and country-level macroeconomic data are collected from the World Bank's *World Development Indicators* database.

[Insert Table 1]

3.2 Measurement of variables

This subsection describes the variables used in the stochastic meta-frontier directional distance function (SMF-DDF) and explaining technical inefficiency. The models are presented in the forthcoming sections. Five sets of variables are used in the models. These are bank outputs, inputs, corporate governance, bank financial characteristics, and country-level banking industry and macroeconomic variables.

[5]The Bankscope database categorises 175 banks from 31 countries as Islamic banks. However, this category includes all Islamic banks, conventional banks with an Islamic window, and other types of non-bank Islamic financial institutions. We include only fully fledged Islamic banks to ensure comparability with conventional banks and to maintain consistency across the sample. GICS are applied to include Islamic banks, and cross-checked with each country's central bank's categorisation of banks. We exclude Iran from our sample because only Islamic banks operate in that country.

The variables related to output quantities and inputs are used in modelling efficiency. Output quantities and inputs are specified following the intermediation approach employed by Sealey and Lindley (1977).[6] The output variables encompass: (i) total amount of customer loans, (ii) other earning assets comprising loans and advances to banks, other securities, derivatives (if any)[7] and other investments; and (iii) non–interest income consisting of net gains (losses) on trading and derivatives, net gains (losses) on other securities, net insurance income, net fees and commissions and other operating income.[8] Inputs include deposits, physical capital and labor. Deposits is measured, as total customer deposits comprising current, savings and term deposits. Physical capital is defined as the bank's fixed assets, and labor is measured by personnel expenses due to unavailability of data for the number of employees for the entire sample. These input measures are commonly used in prior bank studies (e.g. Koutsomanoli-Filippaki et al., 2009; Shamsuddin and Xiang, 2012; Assaf et al., 2013; Rosman et al., 2014).

In addition to regular input-output variables, we include equity capital as a proxy for risk-taking preference in technical efficiency estimation following prior banking studies (Koutsomanoli-Filippaki et al. 2009; Färe et al., 2004; Johnes et al., 2014). Disregarding risk preference may label a bank as being more technically efficient that assumes greater risk to expedite the production process and achieve higher output growth compared to a bank that is more risk averse and chooses to hold more capital to absorb the risk of financial distress (Hughes, 1999; Chen, 2012; Koutsomanoli-Filippaki et al., 2009). Equity capital serves as a quasi-fixed input in the DDF. This approach was also adopted in Koutsomanoli-Filippaki et al. (2009).

[6] Unlike the production approach, the intermediation approach considers banks as financial intermediaries that borrow funds from surplus spending units and transform those funds into profitable projects such as loans and other earning assets. Berger and Mester (1997) argue for using this in bank efficiency estimation because it includes interest expense, which accounts for a significant part of banks' total costs.

[7] We use the dollar value of derivatives as estimated by Bankscope.

[8] Non–interest income is used as a proxy for off–balance sheet (OBS) items as the former is heavily influenced by OBS activities. The omission of OBS items can understate actual bank outputs because they do constitute a significant component of banking business (Clark and Siems, 2002).

As determinants of technical inefficiency, we use variables relating to corporate governance, bank-specific financial characteristics, banking industry and macroeconomic variables. To measure corporate governance, we first use a board governance index for both bank groups. Following Aggarwal et al. (2010), the board governance index is constructed as the average of eight individual attributes of the board of directors.[9] Furthermore, the SSB index is considered as a determinant of inefficiency for Islamic banks. The SSB index is constructed with three attributes of the SSB: size, academic qualifications and reputation of SSB members. SSB size is the total number of SSB members, and academic qualifications of SSB members is the number of SSB members with doctorate degrees, as a percentage of the total SSB members.[10] SSB members' reputation is the number of reputable Shariah scholars on the SSB of a bank, as a percentage of the total SSB members. Reputable Shariah scholars are those who have had or currently have a Shariah directorship position in both or one of the international Shariah standard–setting institutions such as Accounting and Auditing Organizations for Islamic Financial Institutions (AAOIFI), and the Islamic Financial Service Board (IFSB).[11]

With regard to bank-specific variables, the log of total assets is used as a measure of bank size. We measure bank age as the number of years, i.e. from the year of establishment to the end of 2014. The dummy for publicly traded bank is equal to one if a bank's shares are publicly traded on a stock exchange, and zero if otherwise. Following Berger and Mester (1997), we use asset return volatility (SDROA) as a direct measure of bank risk, measured as the three–year rolling standard deviation of net income after tax to total assets. As for banking industry-specific variables, we use bank concentration ratio, measured as the assets of the three

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[9]The board governance index comprises board of directors' attributes related to size, board independence, CEO duality, board members' financial expertise, board members' multiple directorships position, audit committee size, audit committee chairman independence and risk management committee size.

[10]This study follows Berger et al. (2014) by including doctorate degrees as a measure of academic qualifications since these degrees are nested within other academic qualifications, for example MSc or MBA degrees.

[11] The SSB index ($SSBI_i$) is the average of (i) a relative measure of SSB size $[(\text{SSB size}_i - \min)/(\max - \min)]$, (ii) the proportion of SSB members with a doctorate degree and (iii) the proportion of SSB members with good reputations as Shariah scholar; where min and max denote the minimum and maximum SSB sizes.

largest commercial banks, as a percentage of total commercial banking assets. We also include growth rate of per capita GDP as a control variable. Finally, this study includes a time trend variable, which takes the value of 1 for 2003, 2 for 2004 and so on.

3.3 Descriptive statistics

Table 2 presents descriptive statistics. Panels A and B of this table provide descriptive statistics of variables used in the SMF-DDF. On average, the levels of outputs and inputs are lower in Islamic banks when compared with those of conventional banks. The results indicate that Islamic banks have smaller scale of operation than that of their conventional counterparts. The panel C of Table 2 presents the summary statistics of the determinants of technical inefficiency. The average regular board governance score is 58.34 in Islamic banks and 60.41 in conventional banks, which suggests that conventional banks have slightly better board governance system in place than Islamic banks. The average SSB governance score is 35.5 with a standard deviation of 16.7, indicating a considerable cross-sectional variation in SSB governance of Islamic banks. In addition, there are differences in bank size and age between Islamic and conventional banks. Islamic banks are generally smaller in size and younger in age compared to their conventional counterparts. While a typical conventional bank is 32.58 years old, a typical Islamic bank is about half (17.07) that of conventional banks. The percentage of publicly traded banks is 46% for Islamic banks and 53.5% for conventional banks. It is also evident that the mean value of SDROA is higher in Islamic banks compared to conventional banks. Referring to the banking industry-specific variables, we find that on average, 69.63% of banking assets are held by the three largest commercial banks. There is also a standard deviation of 22.21 in the bank concentration ratio. The mean growth rate of per capita GDP is 1.67 with a standard deviation of 4.03, representing a large variation over the sample period.

[Insert Table 2]

4. Technical inefficiency of Islamic and conventional banks

4.1 Directional distance function (DDF)

This study employs the DDF proposed by Chambers et al. (1998). The inputs used by banks are denoted by x = $(x_1, \ldots\ldots, x_N)' \in R_+^N$, where N is the number of inputs and each input in R_+^N is a non-negative real number; and outputs are denoted by y = $(y_1, \ldots\ldots, y_M)' \in R_+^M$, where M is the number of outputs and each output in R_+^M is a non-negative real number. Thus, the set of all technologically feasible input-output combinations for kth bank group can be expressed by the following production technology:

$T^k =$ {(x, y): x can be used by banks in-group k to produce y}, where T refers to technology and k= 1,….., K bank groups. In our case K =2.

For a given direction g = (g_x, g_y), where $g_x \in R_+^N$ and $g_y \in R_+^M$, the DDF for group k can be defined as:

$$\vec{D}_T^k(x, y; g_x, g_y) = \sup\{\beta: (x - \beta g_x, y + \beta g_y) \in T^k\}, \quad (1)$$

where $\vec{D}_T^k$ is the directional technology distance function of a bank group, g_x and g_y refer to the directional vector (g) of inputs (x) and outputs (y), respectively. $\vec{D}_T^k(x, y; g_x, g_y)$ indicates how far (x, y) must be projected along with the direction (g_x, g_y) to achieve the efficient technology frontier of T. Thus, $\vec{D}_T^k(x, y; g_x, g_y)$ provides a measure of technical inefficiency in the DDF, which takes values in the interval (0, +∞) and is equal to zero for a fully technically efficient bank, and positive for a technically inefficient bank. We specify the directional vector as g = (1,1) following Koutsomanoli-Filippaki et al. (2009). This implies that a bank can operate on the efficient frontier by concurrently reducing inputs by β units and increasing outputs by β units along with the direction (1,1).[12] Thus, the DDF allows banks to seek the

[12] Following Koutsomanoli-Filippaki et al. (2009) we set directional vector value equal to zero when equity capital enters in DDF as a quasi-fixed input.

simultaneous maximal expansion of outputs and maximal savings of inputs to reach the efficient boundary of the technology. The DDF can be estimated using its translation property as follows:[13]

$$\vec{D}_T^k(x - \omega g_x, y + \omega g_y; g_x, g_y) = \vec{D}_T^k(x, y; g_x, g_y) - \omega \quad (2)$$

This property means that the translation of input-output vector from (x, y) to $(x - \omega g_x, y + \omega g_y)$ will reduce the distance function value by the scalar ω. Put differently, if inputs are contracted by ωg_x and outputs are expanded by ωg_y, then the value of resulting inefficiency score of DDF, $\vec{D}_T^k(x, y; g_x, g_y)$ will decrease by ω. Since ω is arbitrary, we follow Feng and Serletis (2014) and Malikov et al. (2016) and set the scalar ω equal to the negative of one of the outputs (y_1).[14] Thus replacing ω by $-y_1$ and adding the random noise component, the translation property in equation (2) can be rewritten as a standard stochastic frontier production function:

$$y_1 = \vec{D}_T^k(x + y_1 g_x, y - y_1 g_y; g_x, g_y) + v - u, \quad (3)$$

where v refers to the random error component and u refers to the inefficiency component of the composed error term. To empirically estimate the DDF under the stochastic frontier approach, we use the following quadratic functional form that previous conventional bank studies widely use.[15]

$$y_1 = \alpha_0 + \sum_{n=1}^{N} \alpha_n (x_n + y_1) + \sum_{m=2}^{M} \beta_m (y_m - y_1) + \frac{1}{2}\sum_{n=1}^{N}\sum_{n'=1}^{N} \delta_{nn'} (x_n + y_1)(x_{n'} + y_1) + \frac{1}{2}\sum_{m=2}^{M}\sum_{m'=2}^{M} \rho_{mm'} (y_m - y_1)(y_{m'} - y_1) + \sum_{n=1}^{N}\sum_{m=2}^{M} \varphi_{mn} (y_m - y_1)(x_n + y_1) + v - u, \quad (4)$$

[13] Please see Fare and Grosskopf (2005) for details of the translation property of DDF.

[14] We choose total non-interest income (y_1) as ω. Referring to the treatment of ω, Guarda et al. (2013), Malikov et al. (2016) noted that any input or output can be chosen to be equal to ω. Serra et al. (2011) have reported that parameter estimates change very little with the choice of ω.

[15] Chambers (2002) suggests using this functional form and also followed in Färe et al. (2005), Koutsomanoli-Filippaki et al. (2009), Feng and Serletis (2014); Huang et al. (2015). The quadratic functional form is common choice for DDF since it is easy to impose the translation property with this functional form.

where y_1 is the total non-interest income used as scalar, x_n are the nth inputs where x_1 is the total customer deposits, x_2 is the physical capital measured as the total fixed assets, and x_3 is the labor measured by personnel expenses; y_m is the mth output quantities where y_1 is used as scalar, y_2 is the total loans, y_3 is the other earning assets measured by loans and advances to banks, other securities and other investments; $\alpha, \beta, \delta, \rho, \varphi$ are vector of parameters to be estimated, u is treated as a non-negative random variable represents technical inefficiency of the bank under consideration, and v is a two-sided normally distributed error with a mean of zero and a constant variance σ_v^2, which is assumed to be independent of u. The usual symmetric restrictions are also applied to the second order parameters of the quadratic functional form as, $\delta_{nn'} = \delta_{n'n}, \rho_{mm'} = \rho_{m'm}$. Following Koutsomanoli-Filippaki et al. (2009), we apply the Battese and Coelli (1995) conditional mean model, which permits single-step estimation of the stochastic frontier model to calculate technical inefficiency (u) and the determinants of technical inefficiency.

4.2 Stochastic meta-frontier directional distance function

We use Huang et al.'s (2014) stochastic meta-frontier framework to estimate meta-frontier DDF as followed in Huang et al. (2015). Figure 1 below explains the stochastic meta-frontier DDF model. At a given input (x_1) and output (y_1) levels, the difference between a bank's observed point A and the meta-frontier point A''' consists of three components: the technology gap, TG = $\vec{D}^m - \vec{D}^k$, the random error component v of Equation (4) between points A'' and A', and the group-specific technical inefficiency (u) between points A' and A. Thus, $A''' - A = TG + v + u$

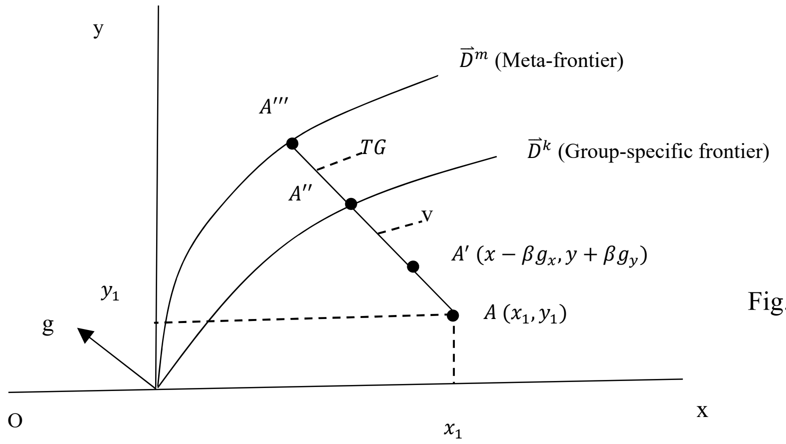

Fig. 1 Stochastic meta-frontier DDF model

To estimate the stochastic meta-frontier DDF, firstly the group-specific stochastic frontier DDF is estimated as in equation (4). In the spirit of group-specific DDF, the meta-frontier DDF can be defined as:

$$\vec{D}^m(x, y; g_x, g_y) = \sup\{\beta^m : (x - \beta^m g_x, y + \beta^m g_y) \in T^m\} \tag{5}$$

Equation (5) differs from Equation (1) in that the reference set of $\vec{D}^k$ in the latter has been replaced by $\vec{D}^m$ in the former to accommodate all bank groups in the meta-frontier. The meta-inefficiency can be shown as:

$$\vec{D}^m(x, y; g_x, g_y) = \vec{D}_T^k(x, y; g_x, g_y) + TG, \tag{6}$$

where the meta-inefficiency $\vec{D}^m(x, y; g_x, g_y)$ with respect to the meta-frontier production technology, is equal to the sum of the group-specific technical inefficiency, $\vec{D}_T^k(x, y; g_x, g_y)$ and the technology gap (TG). The latter reflects a bank group's accessibility to the meta-frontier production technology. The smaller the value of TG, the more advanced technology a bank group undertakes, and hence closer is the group-specific technology frontier to the meta-frontier. The TG in Equation (6) can be reformulated as:

$$\vec{D}_T^k(x, y; g_x, g_y) = \vec{D}^m(x, y; g_x, g_y) - TG, \tag{7}$$

As the true group-k frontier of $\vec{D}_T^k(.)$ is unknown, we calculate its fitted value of $\widehat{\vec{D}^{k*}}(.)$ after estimating Equation (4) by the maximum likelihood estimation (MLE), which leads to:

$$\vec{D}_T^k(x, y; g_x, g_y) = \widehat{\vec{D}^{k*}}(x, y; g_x, g_y) + v^m , \quad (8)$$

where v^m is a random error term arising from the estimation error of the translated group frontiers from (4), which has a mean of zero and a non-constant variance. Substituting Equation (8) into (7), the following estimable stochastic meta-frontier model can be obtained:

$$\widehat{\vec{D}^{k*}}(x, y; g_x, g_y) = \vec{D}^m(x, y; g_x, g_y) + v^m - u^m, \quad (9)$$

where $v^m - u^m$ forms the composite error and u^m is the one-sided error term in the meta-frontier, which represents the technology gap (TG); v^m is the random error. The presence of v^m makes Equation (9) a stochastic, rather than a deterministic. Here, u^m can be explained with a set of bank-specific and environmental variables, which is not possible under a deterministic meta-frontier model suggested by Battese et al. (2004), O'Donnell et al. (2008) and Charnes et al. (1981). We specify the translation property and the functional form for the meta-frontier DDF ($\vec{D}^m$) in Equation (9) in line with Equations (2) and (4), respectively. As before, we also use conditional mean model of Battese and Coelli (1995) to estimate stochastic meta-frontier and the inefficiency terms. Finally, we obtain the meta-inefficiency estimate of Equation (6) as:

$$\text{Meta inefficiency} = \text{group} - \text{specific inefficiency} + TG \quad (10)$$

The meta-inefficiency is the sum of group-specific inefficiency measure (u) and the TG, which enables us to make comparisons of efficiency scores across different bank groups.[16]

[16] The common-frontier framework estimate efficiency ignoring the TG component, assuming that all banks groups operate in the meta-frontier and there is no difference between meta-frontier and group-specific frontier efficiency.

4.3 Empirical results on technical inefficiency

We use the MLE to obtain the parameter estimates of the stochastic efficient frontier and inefficiency determinant models. We find that the majority of the coefficients of equation (4) are statistically significant at the 5% level or less. The contribution of inefficiency to the composite error term of the model is calculated as follows: $\gamma = {\sigma_u}^2/({\sigma_v}^2 + {\sigma_u}^2)$. The average value of estimated γ is close to one for both bank groups, supporting that technical inefficiency component plays an important role in the analysis of bank performance. The log-likelihood ratio (LR) test shows that γ is statistically significant at the 1% level, suggesting the appropriateness of stochastic frontier model in representing our data and confirming the importance of the technical inefficiency effect.[17]

4.3.1 Group-specific technical inefficiency

Table 3 presents technical inefficiency scores for each bank group. Panel A shows that the average group-specific frontier inefficiency score is 0.108 for Islamic banks. The result suggests that a typical Islamic bank can operate on their group-specific efficient frontier by simultaneously decreasing inputs usage by 10.8% and increasing outputs by 10.8%. The mean inefficiency score for conventional banks is 0.168, which can be analogously explained. That is, the input-output mix of a typical conventional bank differs by 16.8% from the best-practice conventional bank in their group-specific efficient frontier. It is worth noting that these inefficiency scores are non-comparable between bank groups because they are estimated from group-specific efficient frontiers.

[17] The full set of results of the estimated parameters of the stochastic directional distance function (the estimates from the main and interactive terms of the outputs, inputs and quasi-fixed input) are not reported. Detailed results are thus available from the corresponding author on request.

4.3.2 *Results of the stochastic meta-frontier DDF estimation*

Panel B of Table 3 reports the technology gap (TG), measured by the deviation of a bank group-specific frontier from the meta-frontier. The mean TG is 0.344 for Islamic banks, indicating that a typical Islamic bank can simultaneously decrease their observed inputs and increase their observed outputs by 34.4% if it adopts the best technology available in the entire banking industry. Conversely, the mean TG is 0.126 for conventional banks, which suggests that the production technology employed by conventional banks is relatively closer to the best technology available to the entire banking industry, and hence they are closer to the meta-frontier compared to their Islamic counterparts.

In Panel C, we report the meta-inefficiency scores for banks, which is the sum of group-specific frontier inefficiency and the TG. Islamic banks' meta-inefficiency is found to be higher than that of conventional banks. Specifically, the average meta-inefficiency is 0.452 for Islamic banks and 0.295 for conventional banks. It is noticeable that compared to conventional banks, Islamic banks have lower group-specific inefficiency score but higher meta-inefficiency score, which can be attributed to their higher technology gap (TG). Thus, the disadvantage in TG outweighs the advantage in lower inefficiency of Islamic banks in group-specific frontier. Our results therefore suggest that bank inefficiency comes not only from the internal operational inefficiency (e.g. managerial inefficiency) but also from the lack of adoption of the best possible technology available to the entire banking industry. Previous studies on Islamic banks (see Table A1) in general estimate inefficiency score without using stochastic meta-frontier framework, which leads to mis-estimation of inefficiency scores because of the omission of the TG component of inefficiency.

Using the paired sample t-test, we find that differences in average TGs and average meta-inefficiency scores between Islamic and conventional banks are statistically significant at the 1% level. Islamic banks' TG and meta-inefficiency are higher than those of conventional banks, thus confirming that Islamic banks operate on a technology frontier that is farther away from the meta-frontier and they are more technically inefficient than that of conventional banks. The results are consistent with hypothesis H_1.

[Insert Table 3]

We also use the two-sample Kolmogorov-Smirnov test of the null hypothesis that the distribution of Islamic banks' inefficiency scores is similar to that of conventional banks. The Kolmogorov-Smirnov test-statistic is significant at 1% level for group-specific inefficiency, TG and meta-inefficiency scores. Thus, we reject the null hypothesis of the equality of the distributions of inefficiency scores between the two bank groups (see Table 3). We further analyse the distribution of group-specific inefficiency, TG and meta-inefficiency scores based on their Kernel density estimates. Figures 2a-2c present the Kernel density estimates of inefficiency scores for the two bank groups. Figure 2a shows that, Islamic banks' group-specific technical inefficiency scores are concentrated at the left tail of the distribution with a negligible proportion of Islamic banks exceeding a group-specific technical inefficiency score of 0.2. However, in Figure 2b, the mass of the distribution of technology gap scores is concentrated to the left of 0.2 for conventional banks, but between 0.2 and 0.4 for Islamic banks. Thus, Islamic banks have higher technology gap, i.e., their group-specific frontier is far away from the meta-frontier when compared with conventional banks. The Kernel density of meta-inefficiency suggests higher meta-inefficiency of Islamic banks than that of conventional banks, as meta-inefficiency scores of the former are more concentrated on the right of the distribution. In general, the results further confirm that higher meta-inefficiency of Islamic banks are attributed to the higher TG instead of group-specific inefficiency. Islamic banks operating within the Shariah boundary may not be able to adopt all available banking technologies. Specifically, Islam's prohibition of interest rates and excessive risk-taking may prevent an Islamic bank from issuing fixed-income securities, securitising its loan portfolio and engaging in derivatives activities.

[Insert Figures 2a-2c]

4.3.3 Time variation in technical inefficiency

Figure 3 presents the cross-sectional average values of group-specific inefficiency, TG and meta-inefficiency for Islamic and conventional banks over the period 2003–2014. Figure 3a presents average group-specific inefficiency measures. Islamic banks' group-specific technical inefficiency fluctuated between 0.08 and 0.11 around a declining trend in the pre-GFC period but slightly increased during the years succeeding the GFC. The group-specific inefficiency score for conventional banks was larger than that of Islamic banks in every year. The inefficiency gap was particularly larger in years surrounding the GFC period.

Figure 3b shows the trends of average TG and meta-inefficiency score. Islamic banks' average TG and meta-inefficiency scores consistently remain above those of conventional banks in all years. The meta-inefficiency gap between the two bank groups was greater in the post-GFC period than in the pre-GFC or the early stage of the GFC. A similar trend was also observed for the technology gap (TG) between Islamic and conventional banks.

[Insert Figures 3a and 3b]

5. What determines technical inefficiency in Islamic and conventional banks?

5.1 Model of inefficiency determinants

We estimate technical inefficiency (u) and its determinants (Z) simultaneously using Battese and Coelli's (1995) one-step procedure. This is in contrast to a two–step procedure where, the first step is to estimate technical inefficiency using stochastic frontier model, and the second step is to estimate how inefficiency (u) levels vary with Z. The one–step procedure is widely recommended as the two-step procedure provides biased estimates at both stages of the procedure (for details see Kumbhakar et al., 1991; Wang and Schmidt, 2002). The technical inefficiency is modelled as follows:

$$u_{it} = Z_{it}\lambda + \varepsilon_{it,} \tag{11}$$

where ε_{it} is the random error term capturing the effects of unobserved factors and is defined by a truncated normal distribution as N (0, ${\sigma_\varepsilon}^2$); λ is a vector of parameters to be estimated; u_{it} is the non-negative truncated inefficiency term; and Z_{it} is a vector of inefficiency determinants. The following specific form of equation (11) is estimated for Islamic banks:

$$u_{it} = \lambda_0 + \lambda_1 SSBI_{it} + \lambda_2 BG_{it} + \lambda_3 BSIZE_{it} + \lambda_4 BAGE_{it} + \lambda_5 PUBT_{it} + \lambda_6 SDROA_{it} + \lambda_7 BC_t + \lambda_8 GDPPC_t + \lambda_9 T + \varepsilon_{it} \tag{12}$$

where, $SSBI_{it}$ is the SSB governance index representing SSB size, academic qualifications of SSB members and the proportion of reputed Shariah scholars on the SSB; BG_{it} is the board governance index constructed with the eight individual attributes of board of directors relating to board composition, and characteristics of the audit and risk management committees; $BSIZE_{it}$ is the size of the bank, which is measured as the log of total assets; and $BAGE_{it}$ is the bank's age, which represents the number of years from the year of establishment to the end of 2014. The age variable captures the efficiency gain through learning-by-doing. PUBT is a dummy variable for publicly–traded banks that is equal to 1 if the bank is a publicly traded bank and 0 if otherwise; $SDROA_{it}$ is the standard deviation of return on assets, representing operational risk.[18] BC_{it} is the bank concentration ratio and refers to the assets of the three largest commercial banks, as a percentage of the total commercial banking assets, which is a proxy of bank competition; $GDPPC_t$ is the growth rate of per capita GDP; and T is

[18] Berger and Mester (1997) argue that the use of SDROA as technical inefficiency determinant overcomes the possible inadequacy of the entire risk coverage by financial capital when included in the inefficiency modelling.

time trend, which takes a value of 1 for 2003, 2 for 2004, etc. The time trend captures the evolving nature of inefficiencies of banks; and ε_{it} is the random error term. We estimate Equation (12) for the sample of Islamic banks. In addition, a restricted version of this equation that omits the SSBI variable is estimated separately for Islamic and conventional banks.

5.2 Results on the determinants of technical inefficiency

In Panel A of Table 4, we present the determinants of Islamic banks' group-specific technical inefficiency. Islamic banks with a higher SSB governance have a lower technical inefficiency than other Islamic banks, supporting our hypothesis H_{2b}.[19] An increase in the regular board governance index increases Islamic banks' technical inefficiency. Larger Islamic banks are more technically inefficient than smaller ones. The result supports finding of a negative relationship between size and efficiency reported in earlier studies (e.g. Isik and Hassan, 2002; Abdul-Majid et al., 2010; Johnes et al., 2014). Technical inefficiency decreases with bank age, supporting the argument of efficiency gain through learning-by-doing (Mester, 1996). The publicly-traded Islamic banks tend to have lower technical inefficiency compared to their non-traded counterparts. More specifically, publicly traded Islamic banks are 2.42% less inefficient than that of non-traded Islamic banks. The coefficient of asset return volatility (SDROA) is negative and statistically significant, indicating that higher risk-taking reduces inefficiency. This is consistent with previous evidence of conventional banks (Berger and Mester, 1997; Maudos et al., 2002).

The bank concentration ratio has significant positive influence on Islamic banks' technical inefficiency but the growth rate of per capita GDP has no significant effect. The former result is consistent with the finding of Johnes et al. (2014) and supports the 'quiet life'

[19] In a separate model, we also examine the effects of three individual SSB attributes on technical inefficiency. Our results show that larger SSB size and academic qualifications of SSB members reduce technical inefficiency but SSB members' reputation is not significantly related to technical inefficiency. Detailed results are available from the corresponding author on request.

hypothesis, i.e. banks in more concentrated markets face less competitive pressure to achieve higher efficiency. Our result also shows that the technical inefficiency of Islamic banks does not present a statistically significant linear trend after controlling for the effects of other explanatory variables. We re-estimate Islamic banks' inefficiency model, omitting the SSB index from Equation 12. Our previous results hold for all determinates except for SDROA, bank concentration and growth rate of per capita GDP.

Panel B of Table 4, reports the results on the determinants of group-specific technical inefficiency for conventional banks. The better board governance is associated with higher technical inefficiency, a result similar to our prior result obtained for Islamic banks. The finding supports our hypothesis H_{2a}. The effect of bank size on technical inefficiency of conventional banks is also similar to that of Islamic banks. While the effect of bank age is negative for Islamic banks, it is positive for conventional banks. The latter result suggests that older conventional banks are more inefficient, which supports the view that the rate of return on experience is negative (Chen, 2012; DeYoung and Hasan, 1998). The publicly traded conventional banks appear to be more technically inefficient than that of non-traded banks. A positive relationship between inefficiency and SDROA is found for conventional banks, which is consistent with Berger and DeYoung's (1997)–bad management hypothesis. Bad management underperforms both in banking operations as well as in controlling risk. Koutsomanoli-Filippaki et al. (2009) also find similar results with the risk-inefficiency nexus. The result supports our previous result for Islamic banks when we omit the SSB index as a determinant of inefficiency but contradicts the result obtained from a model with the SSB index, indicating that SSB as an additional layer of governance in Islamic banks helps in disciplining bad managers.. Technical inefficiency decreases with an increase in bank concentration and increases with the growth rate of per capita GDP. The latter result is consistent with Dong et al.'s (2017) study that finds higher bank inefficiency when the economy is growing. There is no statistically significant liner time trend in technical inefficiency of conventional banks.

Panel C of Table 4 describes the results for the determinants of the technology gap (TG), estimated from the one-sided error term of the stochastic meta-frontier DDF model. Our results show that, better board governance increases the TG, supporting the view that managers of banks with good governance practices are less inclined to adopt new production technology due to the fear of being fired if new technology fails to perform (Balsmeier et al., 2017). The TG decreases with an increase in bank age but not significantly associated with bank size. The TG is more in publicly traded banks compared to privately owned banks. TG is also higher in banks involved in higher risk-taking, indicating that higher risk-taking counterweight the benefit of adopting potential technology. The banking industry concentration and the growth rate of per capita GDP have negative influence on the TG. There is no statistically significant linear time trend in TG.

[Insert Table 4]

6. Additional tests

6.1 Common frontier estimation and technical inefficiency

In this section, we examine the robustness of our prior results by estimating efficiency of Islamic and conventional banks under a common frontier framework, which pool together all the data of both bank groups, assuming that they operate under a single frontier and share similar technologies. The results are tabulated in Table 5. We find that the use of a common frontier framework underestimates technical inefficiency levels compared to meta-frontier results as reported in Table 3. For instance, the mean of Islamic banks' meta-inefficiency is 0.452 while common frontier inefficiency score is 0.220. Furthermore, conventional banks' average inefficiency score obtained from the common frontier is 0.197 compared to the mean of 0.295 in the meta-frontier model. The common frontier underestimates inefficiency scores for both bank groups, which is attributable to the assumption that all bank groups operate in the meta-frontier and hence no technology gap (TG) exists between the meta-frontier and the group-specific frontier of each bank group. However, the finding that Islamic banks are more inefficient than conventional banks remains valid regardless of whether we use a meta-frontier or a common frontier.

[Insert Table 5]

6.2 Technical inefficiency by geographical regions

We also examine technical inefficiency of Islamic and conventional banks across six geographical regions. These regions vary with respect to legal and regulatory support to promote Islamic banking, interpretation of Shariah law and demand for Shariah compliant banking services, which may result bank inefficiency. To allow for regional differences in inefficiency levels, we divide our full sample in six regions and estimate region-wise inefficiency scores for both bank groups. The results are presented in Table 6. The results for geographic regions are in line with those of the whole sample of countries. In general, Islamic banks have lower inefficiency in their group-specific frontier but have higher TG compared to conventional banks, which results in higher meta-inefficiency in all six regions. However, there are considerable variations of Islamic banks' inefficiency scores across regions. Islamic banks in South Asia region are less technically inefficient followed by Sub-Saharan Africa, East Asia & Pacific, non-GCC Middle East & North Africa, Europe & Central Asia, GCC regions. Our results confirm Rosman et al. (2014) and Johnes et al.'s (2014) finding on higher efficiency of Asian countries' Islamic banks than that of Middle Eastern countries' Islamic banks. Conventional banks in GCC, East Asia & Pacific, Europe & Central Asia regions have higher group-specific inefficiency scores compared to TG scores, but the scores are reverse for other three regions. The results suggest that the adoption of potential technology in providing banking intermediation services is of an issue in latter three regions rather than improvement in managerial capabilities to promote group-specific efficiency.

[Insert Table 6]

6.3 Endogeneity in efficiency-corporate governance relationship

In this section, we control for the potential endogenous relationship between corporate governance variables (e.g. SSB governance, board governance) and efficiency. The issue of endogeneity may be of concern in this context since simultaneity can arise in the corporate governance and efficiency relationship. We address the endogeneity issue using an instrumental variable for each corporate governance variable. To construct instrumental variables, we use the approach followed in John et al. (2008), Laeven and Levine (2009) and Aggarwal et al. (2010). More specifically, an instrument of a corporate governance variable for a candidate bank is constructed with the year-average of that variable in all other banks in the country. The use of such an instrumental variable is reasonable as the corporate governance of other banks is likely to be correlated with corporate governance of the focus bank but uncorrelated with the focus bank's inefficiency. The estimation is conducted with the two-stage least square (2SLS) estimator[20] and the results are presented in Table 7. Panel A, shows that better SSB governance reduces technical inefficiency in Islamic banks. However, better regular board governance increases their technical inefficiency. The inefficiency effect of regular board governance is similar for conventional banks (see Panel B). Better board governance also increases technology gap (see Panel D). These results confirm our main findings as reported in Table 4.

[Insert Table 7]

[20] For regressions with instrumented governance variables, we include countries with more than one Islamic bank.

7. Conclusion

This study examines the technical efficiency of Islamic vis-à-vis conventional banks. The extant studies on Islamic banks' technical efficiency typically employ either an input-oriented or an output orientated distance function and estimate technical efficiency of Islamic and conventional banks under a common stochastic or DEA efficiency frontier. We contribute to the literature by using a directional distance function (DDF) under a stochastic meta-frontier (SMF) framework to compare technical efficiency between the two bank groups. The DDF is a better choice for efficiency estimation compared to Shephard's input or output oriented distance function, since the DDF facilitates estimation of efficiency under concurrent reduction of inputs and expansion of outputs. The use of a stochastic meta-frontier model enables us to evaluate meta-inefficiency of two bank groups incorporating the divergences in their group-specific efficient frontiers and access to the potential technology available to the entire banking industry. In addition, this study fills a void in the literature by investigating whether regular board governance and SSB governance influence the technical efficiency of Islamic banks.

We find that Islamic banks generally have lower levels of technical inefficiency compared to the best-practice banks that operate on their group-specific frontier. However, Islamic banks have a higher technology gap, which leads to a higher meta-inefficiency level in comparison with their conventional counterparts. Additionally, this study reveals that SSB governance is conducive to reducing technical inefficiency of Islamic banks. However, improved regular board governance increases technical inefficiency of both bank groups. Our key findings on the governance-inefficiency relationship are robust to controlling for potential endogeneity of corporate governance. Our results imply that a stochastic common frontier would underestimate technical inefficiency for both bank groups.

The findings of this study are of particular importance to bank managers and policy makers. As the group-specific technical inefficiency is less than technology gap in Islamic banks, managerial inefficiency is of second order importance relative to technology gap. Hence, bank managers should adopt financial innovations to catch up with the best possible technology so that they can operate on an efficient frontier closer to the meta-frontier. For conventional banks, the group-specific technical inefficiency is higher than technology gap, implying that conventional banks should promote managerial capabilities more to have higher group-specific efficiency. Domestic regulatory bodies and international standard setting bodies of Islamic banks (e.g. IFSB, AAOIFI) may find our evidence useful in developing a banking landscape conducive to Islamic banks' efficiency. For example, Islamic banks may be able to decrease their technology gap if these bodies can formulate regulatory guidelines that allow Islamic banks to adopt innovative banking technologies without compromising Islamic principles.

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Table 1 Sample countries, banks and observations

Region/Country	Number of banks	Observations	Percentage of observations
Gulf-Cooperation Countries (GCC)			
Bahrain	18	164	12.91
Kuwait	10	78	6.14
Oman	4	8	0.63
Qatar	8	50	3.94
Saudi Arabia	8	50	3.94
United Arab Emirates	14	92	7.24
Non-GCC Middle East & North Africa			
Egypt	2	12	0.94
Iraq	6	24	1.89
Jordan	6	40	3.15
Lebanon	2	8	0.63
Palestine	2	12	0.94
Syrian Arab Republic	4	18	1.42
Tunisia	2	10	0.79
Yemen	2	18	1.42
Sub-Saharan Africa			
Kenya	4	20	1.57
Nigeria	2	6	0.47
South Africa	2	14	1.10
Sudan	10	46	3.62
Europe and Central Asia			
Turkey	8	74	5.83
United Kingdom	6	44	3.46
East Asia & Pacific			
Malaysia	26	202	15.91
Indonesia	6	40	3.15
Brunei Darussalam	2	10	0.79
Thailand	2	14	1.10
South Asia			
Bangladesh	14	94	7.40
Maldives	2	8	0.63
Pakistan	14	106	8.35
Sri Lanka	2	8	0.63
Total 6 regions & 28 countries	188	1270	100

Notes: This table presents the list of total sample countries, number of banks and bank-year observations. The sample includes an equal number of Islamic and conventional banks from each country.

Table 2 Descriptive statistics of variables

Variable names	Variable notations	Unit of measurement	Islamic banks Mean	Islamic banks Std. Dev.	Conventional banks Mean	Conventional banks Std. Dev.	t-statistics
Panel A: Output quantities							
Total non-interest income	y_1	million USD	73.91	165.16	163.88	262.03	-7.90***
Total loans	y_2	million USD	3514.70	6714.52	8650.87	12740.82	-10.07***
Other earning assets	y_3	million USD	1366.49	2441.06	4169.24	5708.21	-12.15***
Panel B: Inputs							
Total deposits	x_1	million USD	3962.78	7105.42	9749.94	13404.30	-9.61***
Physical capital	x_2	million USD	100.16	306.67	124.98	203.00	-1.70 *
Labour	x_3	million USD	52.53	90.91	109.35	167.37	-7.52**
Quasi-fixed input							
Equity capital	x_4	million USD	732.61	1360.11	1652.02	2422.76	-8.33***
Panel C: Determinants of inefficiency							
SSB governance index	SSBI	%	35.5	16.70			
Board governance index	BG	%	58.34	20.67	60.41	19.15	-2.42**
Bank size	BSIZE	log	3.27	0.72	3.60	0.82	-10.65***
Bank age	BAGE	integer	17.07	11.48	32.58	24.13	-15.00***
Publicly-traded banks	PUBT	dummy	0.46	0.49	0.53	0.49	3.96***
Standard deviation of ROA	SDROA		1.104	1.981	0.889	2.251	1.839*
Bank concentration	BC	%	69.63	22.21			
Growth rate of per capita GDP	GDPPC	%	1.67	4.03			

Notes: This table presents the descriptive statistics of variables used in modelling technical inefficiency in Panels A and B and their determinants in Panel C, respectively. ***, ** and * indicate statistical significance at the 1%, 5% and 10% levels, respectively.

Table 3 Summary statistics of inefficiency scores estimated from the stochastic meta-frontier model

	Mean	Std. Dev.	Min	Max	t-statistics	Kolmogorov-Smirnov test
Panel A: Group-specific inefficiency						
Islamic banks	0.108	0.096	0.008	0.625		
Conventional	0.168	0.129	0.000	0.724	-9.473***	5.528***
Panel B: Technology gap (TG)						
Islamic banks	0.344	0.145	0.000	0.802		
Conventional	0.126	0.081	0.000	0.892	3.073***	2.025***
All banks	0.235	0.160	0.000	0.892		
Panel C: Meta-inefficiency						
Islamic banks	0.452	0.179	0.023	1.018		
Conventional	0.295	0.153	0.000	1.596	6.789***	7.184***
All banks	0.373	0.184	0.000	1.596		

Notes: This table presents the group-specific technical inefficiency of Islamic and conventional banks in Panel A and technology gap (TG) scores in Panel B. These are obtained from the group-specific frontier and stochastic meta-frontier, respectively. The meta-inefficiency in Panel C is the sum of group-specific technical inefficiency and technology gap scores. ***, ** and * indicate statistical significance at the 1%, 5% and 10% levels, respectively.

Figure 2 Kernel density estimates of technical inefficiency

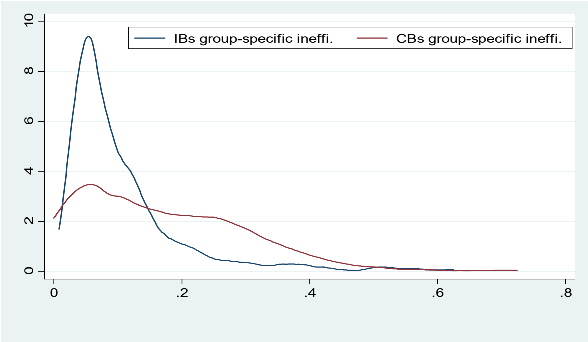

Fig. 2a Technical inefficiency in group-specific frontier

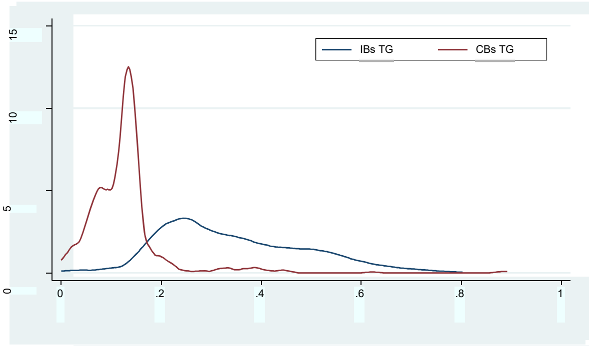

Fig. 2b Technology gap (TG) in stochastic meta-frontier

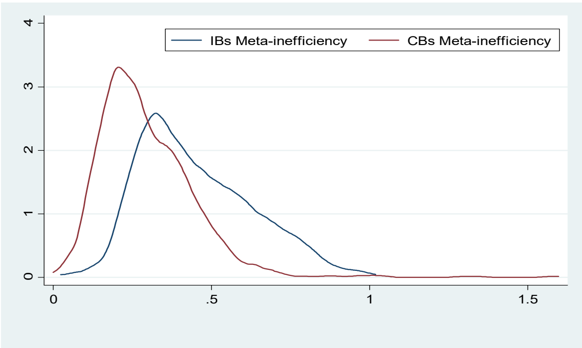

Fig. 2c Meta-inefficiency in stochastic meta-frontier

Notes: These figures present the Kernel density of technical inefficiency scores for Islamic and conventional banks. The technical inefficiency scores in Figure 2a are estimated from group-specific stochastic frontier directional distance function model. The technology gap and meta-inefficiency scores in Figures 2b and 2c respectively are estimated from stochastic meta-frontier directional distance function model. The Kernel density estimation uses automatically defined bandwidth in STATA (version 12).

Figure 3 Trends of various inefficiency measures

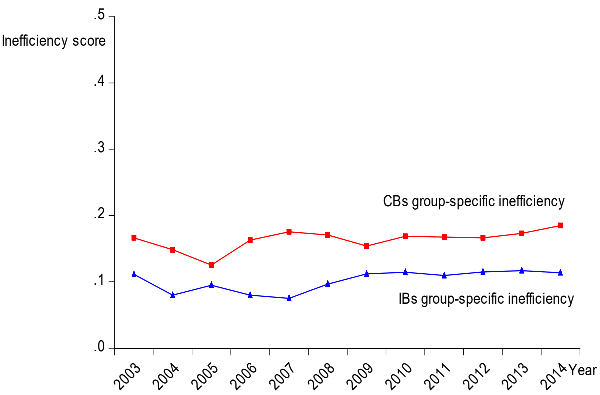

Fig. 3a Trends of bank group-specific inefficiency scores

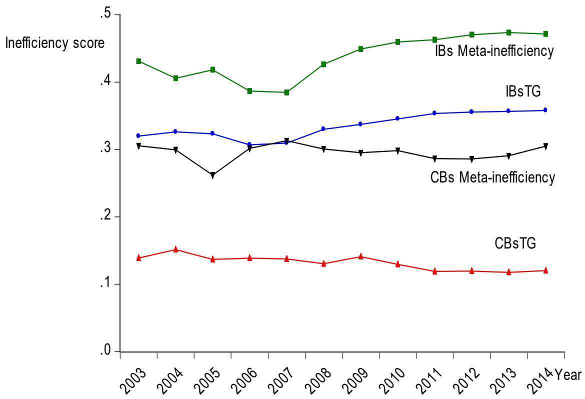

Fig. 3b Trends of technology gap and meta-inefficiency scores

Notes: The figure 3a presents the trends of group-specific technical inefficiency scores for Islamic and conventional banks groups. The figure 3b presents the trends of technology gap and meta-inefficiency scores for both bank groups obtained from the stochastic meta-frontier estimation.

Table 4 Determinants of group-specific technical inefficiency and technology gap (TG)

Variables	Panel A: Group-specific inefficiency in Islamic banks		Panel B: Group-specific inefficiency in conventional banks	Panel C: Technology gap: SMF framework
Corporate governance variables				
SSB governance	-4.835***			
Board governance	1.148***	0.910***	0.721***	0.0167**
Bank and country-level variables				
Bank size	1.841***	1.950***	1.019**	0.032
Bank age	-0.489**	-0.552**	0.659***	-0.030**
Publicly-traded banks dummy	-2.417***	-2.512***	1.262***	0.011***
SDROA	-0.981**	2.264*	1.37*	1.58***
Bank concentration	0.710***	-0.173*	-0.543***	-0.098*
Growth rate of per capita GDP	0.543	-1.97***	2.993***	-0.010**
Time trend	2.589	5.560	-8.303	0.023
Constant	-1.67***	-3.546***	-4.37***	0.0015

Notes: This table presents the results on determinants of group-specific technical inefficiency in Islamic and conventional banks in Panels A and B, respectively. Panel C reports the determinants of technology gap represented by the one-sided error term in SMF regression. ***, ** and * indicate statistical significance at the 1%, 5% and 10% levels, respectively.

Table 5 Summary statistics of inefficiency scores based on the common-frontier model

		Std.	Min	Max
Islamic banks	0.220	0.205	0.000	0.995
Conventional	0.197	0.152	0.000	0.839
All banks	0.208	0.181	0.000	0.995

Notes: This table presents the technical inefficiency scores of Islamic and conventional banks obtained from the common frontier framework. The common frontier framework assumes that both bank groups operate under a common efficient frontier and there is no technology gap between bank groups.

Table 6 Summary statistics of inefficiency measures by geographical region

	Panel A: Islamic banks			Panel B: Conventional banks		
	Group-specific inefficiency	Technology gap	Meta-inefficiency	Group-specific inefficiency	Technology gap	Meta-inefficiency
GCC	0.121	0.351	0.471	0.219	0.112	0.331
East Asia &	0.185	0.256	0.441	0.155	0.112	0.267
Europe & Central	0.062	0.391	0.454	0.260	0.163	0.423
Non-GCC MENA	0.086	0.357	0.443	0.099	0.157	0.256
Sub-Saharan	0.054	0.304	0.359	0.071	0.125	0.196
South Asia	0.047	0.297	0.344	0.115	0.134	0.249

Notes: This table presents the summary statistics of Islamic and conventional banks' technical inefficiency measures across six geographic regions in Panels A and B respectively. Meta-inefficiency is the results of both group-specific inefficiency and technology gap.

Table 7 Bank inefficiency and corporate governance: IV estimation

Variables	Panel A: Group-specific inefficiency in Islamic banks		Panel B: Group-specific inefficiency in conventional banks	Panel C: Technology gap: SMF framework
Corporate governance variables				
SSB governance	-0.034**			
Board governance	0.0023***	0.0021***	0.0004*	0.008*
Bank and country-level variables				
Bank size	0.0504***	0.0503***	0.0762***	0.0031
Bank age	0.0007	-0.0007	0.0005***	-0.002***
Publicly-traded bank dummy	-0.0407***	-0.0402***	0.0487***	0.0222**
SDROA	-0.0033*	-0.0037*	0.002	0.007***
Bank concentration	0.0007***	0.0007***	0.0001	0.0005**
Growth rate of per capita GDP	-0.0014*	-0.0014*	0.0009	-0.0002
Time trend	0.0011	0.0012	0.0019	0.0026
Constant	-0.2069***	-0.2107***	-0.1947***	0.2064***
R-squared	0.312	0.332	0.409	0.074

Notes: This table presents the results on determinants of group-specific inefficiency in Islamic and conventional banks in Panels A and B, respectively. Panel C reports the determinants of technology gap represented by the one-sided error term in SMF regression. In all panels, we use instrumented corporate governance variables. The post-estimation test results on the endogeneity of governance variables and the strength of instrument are significant at the 1% level, thus rejecting the null hypothesis that variables are exogenous and instruments are weak. ***, ** and * indicate statistical significance at the 1%, 5% and 10% levels, respectively.

Appendix Table A1 Summary of differences between our study and the closest previous studies on Islamic banks' technical efficiency

Panel A: Prior literature				Panel B: Research gaps			
Authors	Efficiency estimation method and sample	Bank, country-level variables effects	Key findings	Directional distance function (DDF)	Stochastic meta-frontier (SMF)	Board governance effects	SSB effects
Islamic and conventional banks' efficiency: studies focus on multi-countries							
Abdul-Majid et al. (2010)	SFA, ODF (23 IBs, 88 CBs, 1996-2002, 10 countries)	Yes	Islamic banks are less efficient compared to conventional banks.	No	No	No	No
Ahmad and Luo (2011)	DEA, IDF (9 IBs, 33 CBs, 2005-2008, 3 countries)	Yes	Islamic banks are more efficient compared to conventional banks.	No	No	No	No
Mobarek and Kalonov, (2014)	DEA, SFA, IDF (101 IBs, 307CBs, 2004-2009, 18 countries)	Yes	Islamic banks are less efficient compared to conventional banks.	No	No	No	No
Johnes et al. (2014)	ODF, DEA, meta-frontier (45 IBs, 207CBs, 2004-2009, 18 countries)	Yes	There are no significant differences in overall efficiency between Islamic and conventional banks. Islamic banks have higher net but lower type efficiency.	No	No	No	No
Islamic and conventional banks' efficiency : studies focus on single country							
Hassan and Abdul-Majid (2011)	DEA, ODF (2 IBs, 10 CBs, 12 Islamic window banks, 2000-2008, Malaysia	Yes	Islamic window banks' exhibit higher efficiency followed by Islamic banks and conventional banks.	No	No	No	No
Wanke et al. (2016a)	TOPSIS (16 IBs, 27 CBs, 2009-2013, Malaysia)	Yes	Islamic banks have lower efficiency levels and slacks compared to conventional one.	No	No	No	No
Azad et al. (2016)	Malmquist meta-frontier (16 IBs, 27 CBs, 2009-2013, Malaysia)	Yes	Islamic banks outperformed conventional banks.	No	No	No	No
Batir et al. (2017)	DEA, IDF (4 IBs, 27 CBs, 2005-2013, Turkey)	Yes	Islamic banks are more efficient compared to conventional banks.	No	No	No	No
Studies focus on Islamic banks' efficiency only							
Sufian et al. (2009)	DEA, IDF (37 IBs, 2001-2006, 16 countries)	Yes	Islamic banks in Middle Eastern countries are more efficient than that of Asian countries Islamic banks.	No	No	No	No
Rosman et al. (2014)	DEA, IDF (76 IBs, 2007-2010, 19 countries)	Yes	Islamic banks in Middle Eastern countries are less efficient than that of Asian countries Islamic banks.	No	No	No	No
Belanès et al. (2015)	DEA, IDF (2005-2011, 30 IBs, 5 GCC countries)	Yes	Islamic banks in GCC countries exhibit different levels of efficiency with highest levels of efficiency in UAE banks. Islamic banks efficiency levels decline during the GFC.	No	No	No	No
Wanke et al. (2016b)	TOPSIS and neural networks approach (2010-2014, 114 IBs, 24 countries)	Yes	Islamic banks efficiency levels are stable over the study period but vary across countries.	No	No	No	No
This study	**Stochastic meta-frontier, Directional distance function, (94 IBs, 94 CBs, 2003-2014, 28 countries)**	**Yes**		**Yes**	**Yes**	**Yes**	**Yes**

Notes: This table presents a summary of differences between our study and the closest previous studies on Islamic banks' technical efficiency. Panels A and B describe prior literature and research gaps in Islamic banking efficiency literature respectively. SFA refers to the stochastic frontier analysis, DEA is the data envelopment analysis, ODF is the output distance function, IDF is the input distance function, TOPSIS is the technique for order preference by similarity to the ideal solution, SSB is the Shariah supervisory board, IBs is the Islamic banks and CBs is the conventional banks. No means not being investigated in previous studies and Yes represents the alternative.