



Revisiting Islamic banking efficiency using multivariate adaptive regression splines

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Abstract

Islamic banking is among rapidly-growing components in the world's financial system. Within its institutions, continuous criteria of efficiency facilitate the evaluation of the impact of the reforms and policies on the banks' performance. In this paper, we employ the Multivariate Adaptive Regression Splines (MARS) method for estimating the efficiency of Islamic banks in developed and developing countries. MARS is a well-known efficient method for the flexible modelling of high-dimensional data. Unlike previous work, using a nonparametric technique of such a robustness instead of parametric approaches contributes to the improvement of the various estimates, which provides investors with accurate and timely information they can immediately react upon for a better decision-making in turbulent times. On the one hand, the results of the experiments show that, in the emerging region, there is evidence of a strong linkage between Islamic banking efficiency and gross domestic product. On the other hand, in the developed region, the efficiency is rather based upon Sharia Supervisory Board and board committees. These outcomes confirm previous works showing that governance-related variables have a significant positive effect on Islamic banking efficiency. Furthermore, the overall MARS-based predictions reveal that Islamic banks operating in developed countries are relatively more efficient than their counterparts in emerging countries.

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1 Introduction

Efficiency in Islamic banks is not only a very large and fast growing industry, but also an especially complicated research matter. According to Iqbal and Molyneux (2005), studying the efficiency of Islamic banks is important for the following reasons. First, improving the cost-efficiency leads to higher profits and to increasing the chance of survival in deregulated and competitive markets. This is particularly important for Islamic banks as they compete face-to-face with conventional banks in different ways. Second, a consciousness of efficiency dimensions is important to allow policy-makers to convey policies that mark the entire field of banking. Finally, customers are interested in knowing the prices/quality of bank services, which are strongly influenced by a bank's overall efficiency of operations. At the same time, the governance-related efficiency of banks can be approached in several different ways. According to Hassan et al. (2005), governance¹ is mainly devoted to reduce the inefficiencies that arise from moral hazards and inadequate selection. Therefore, it is crucial to develop new efficiency measures that comply with Shariah. Hence, the application of the concept of amanah (trust) to a business situation presupposes that the business is managed by those responsible as a trusteeship for the stakeholders but above all aware of the evolution of the various risks and governance measures. In view of this reliance on amanah, financial governance is ensured and unethical behaviour is avoided. Nevertheless, the problem of the effect of governance on Islamic banks efficiency has been rarely addressed in previous works. This is quite understandable since Islamic banks have specific features when compared with conventional banks, given that Islamic banks are under the law of Sharia. Therefore, their governance should be quite different from that in conventional banks. Islamic or ethical financing respects Muslims' laws and simply owes its genesis to the Coran and the Sunna.

Over the past few decades, the Islamic banking sector has rapidly grown and has become one of the greatest industries in the banking sphere. According to the statistics of the World Bank² in 2020, the global Islamic finance market recently passed the \$2 trillion mark in assets and is expected to reach around \$3.5 trillion by 2021. Moreover, although the growth of Islamic finance in developed countries is still not adequately developed, meeting the banking needs of the Muslim populations of these countries represents an important opportunity for future growth. Therefore, the efficiency of these banks is a necessary factor for their rapid growth, regardless of their location. Traditionally, Islamic banking efficiency was especially measured using the return on asset (ROA) and the return on equity (ROE) to define the impact of financial determinants on the efficiency. In addition, academic literature has shown that there are many relationships between governance and banking efficiency. In this sense, the soundness of the Sharia advice is expected to improve the profit efficiency (Safiullah & Shamsuddin, 2019) and the financial performance of Islamic banks (Farag et al., 2018; Mollah & Zaman, 2015). On this basis, Bourakba (2014) suggested that there is a very strong relationship between governance-related variables and Islamic banking performance.

¹ See Hopt (2021).

² <https://www.worldbank.org/>.

In literature, the importance of Islamic banking efficiency has been widely addressed over the past few decades, where it was especially compared with the conventional one (Samad et al., 1999; Abdul-Majid et al., 2010). An important part of the works has paid particular attention to Islamic banking efficiency in developed and emerging countries (Abduh et al., 2013 and Rosman et al., 2014) since this topic is likely to trace the fitting sources of inefficiency, and can consequently help banks to improve their chances of survival in competitive markets (Ihsan and Kabir, 2002). In addition, since Islamic finance involves several activities such as Islamic insurance agencies and Zakat agencies, Islamic banking is double-missioned (socially and economically). It provides social products/goods whose aim is to encourage young investors through support products such as *Al-mocharaka* and *Al-moudharaba*. It therefore contributes to the increase of investments, thus leading to the rise of economic growth. This social responsibility offers three major advantages; it guarantees the long-term performance of Islamic banks (Platonova et al., 2018), leads to getting a better performance (Ahmed, 2010) and being a basic component in the economic growth. The latter is strongly a positive aspect in the development of Islamic banks in Muslim countries (Mensi et al., 2019). In equity markets, Islamic banks have achieved great successes in emerging economies in comparison with their conventional counterparts, especially over the main global financial crises (Boubakri et al., 2019). Such a success reveals, in fact, that Islamic banks represent an actual cornerstone in the economy of developing countries. Moreover, in spite of the big challenges in western countries, they remain sufficiently strong and on the way to gain an important position in non-Islamic countries (Bitar et al., 2017).

Furthermore, in order to reveal the significant sources of Islamic banking inefficiency, including the problems and obstacles encountered by researchers to highlight efficiency-related Islamic banks weaknesses, several among their determinants have been established with the help of the empirical studies in both emerging and developed economies. Besides, to help better-fit models, which in most cases were linear multivariate, economic control variables were continuously included. The most useful among these variables were measures of national economic growth and development. Historically, the link between financial development and economic growth has been widely emphasized over the past decades in the academic literature of economists. According to the numerous studies carried out in this field, Islamic banking contributes positively to the economic growth. A study by Anwar et al. (2020) aiming to examine the link between Islamic banks and the Indonesian economy showed that there is a significant positive link between the economic growth and these banks in the short or long run. In addition, Chowdhury et al. (2012) showed that Islamic banks in Bangladesh have a significant positive relationship and an important contribution to the economic growth of the country. In the same vein, according to Kassim (2016), who investigated a sample of Malaysian banks, Islamic finance has started to make significant contributions to the real economy. Boukhatem and Moussa (2018) showed that, during the period 2000–2014, Islamic banking contributed to economic growth in the countries of the MENA region. On the other hand, Bitar et al. (2017) have shown that, despite the challenges faced by Islamic banks in Western countries, they remain strong as they are trying to gain an important place in non-Islamic countries thanks to their quality of efficiency.

On the technical level, the most commonly used methods in Islamic banking modeling are accountancy ratios, parametric methods such as SFA (Stochastic Frontier Approach) and TFA (Thick Frontier Approach). Other important approaches have been employed in this context such as non-parametric methods, some of which are the well-known data envelopment analysis (DEA) method and the Free Disposal Hull (FDH) method. On the other hand, while it is rarely used in the financial field, data-mining has never been used in the Islamic banking framework, especially to highlight the impact of governance on Islamic banking efficiency.

This set of tools can be classified among the nonparametric approaches and has been mainly used in the fields of medicine (Saâdaoui et al., 2015; Tsumoto and Hirano, 2016; Zonouzi and Kargari, 2020), transportation sciences (Khosravi et al., 2020), optics (Yucel et al., 2020) and conventional finance (Aburrous et al., 2010; Bhambri, 2011; Saâdaoui, 2012; Liébaná-Cabanillas et al., 2013; Soumya & Deepika, 2016; Peral et al., 2017; Miyan, 2017; Cai & Zhang, 2020), etc. According to recent surveys and simulation studies, data-mining is proven enough robust for providing valuable, efficient and accurate prediction and forecasting results.

It should also be remembered in this context that the evolution of data management and storage technology over the few last decades has revitalized complex multi-dimensional data modeling. Since then, many algorithmic and learning approaches have been developed. On the other hand, in several fields such as in finance and economics, it has been proven too restrictive to admit classical standard hypotheses, some of which are linearity, stationarity, independence, and standardly distributed returns. In fact, the majority of phenomena arising in nature can be more conveniently be considered as non-linear in both position and dispersion. Examples include but are not limited to chaotic, fractal, and multimodal data. The alternative to classical econometric models has been data-mining and machine learning (ML) systems (Aburrous et al., 2010; Anouze & Bou-Hamad, 2021; Rabbouch et al., 2018; Yucel et al., 2020; Zhu et al., 2019).

Nowadays, this new generation of methods is increasingly introduced in different disciplines of finance and banking (Bhasin, 2006; Saâdaoui & Ben Messaoud, 2020; Saâdaoui et al., 2017). Thanks to their practical implementation, they are effectively used for classifying, regressing and forecasting financial and econophysical data. Among the best-known DM-ML approaches, multivariate adaptive regression splines (MARS) are especially used for automatically modeling nonlinearities and interactions between variables. Another strength of this method is its capacity to handle multiple dependent variables. This is the main reason behind its use in this paper. It is in fact one of the main contributions of our paper to revisit this important question of estimating banking efficiency in a data-mining modeling framework. Unlike many of the previous attempts, no parametric model is assigned in advance. Rather, it is a task of piecewise statistical recognition of the shape that is applied. It is therefore obvious that the estimates obtained at the end of our experiments will be less biased than those got from conventional econometric models. It is noticeable that, in the context of financial data-mining, this type of models has already been applied with great efficiency (Affes et al., 2019; Kalaycı et al., 2020; Özmen, 2021). Indeed, these models have become an indispensable tool not only for researchers, but also for analysts of financial markets, who use them in banking operations, asset pricing and in evaluating portfolio risk. For policymakers, employing such a type of accurate models in several areas help better evaluate the impact of the adopted reforms and policies on the banking sector performance. In the current context of Islamic banking efficiency, the use of a robust model such as MARS will allow us to accurately reassess the contribution of different involved regressors, and in particular those linking governance to efficiency.

In this paper, we propose a new background for assessing the influence of governance on Islamic banks' efficiency. Developed and emerging economies are both concerned in this investigation, where a data mining approach is applied for estimating this multivariate model. With the support of a number of significant economic control variables, an appropriate modeling allows us to identify potential sources of efficiency as well as inefficiency for Islamic banks. In this analysis, we mainly intend to answer the following question: in a purely nonparametric modeling framework, what impacts does governance have on developed and emerging countries? In other words, what is the linear or nonlinear link between governance and efficiency? To answer this question, we estimate the efficiency of banks in developed and

emerging countries by firstly integrating four conventional measures of corporate governance (CBD, SBD, BC and COW) and an Islamic index measuring governance (SSB). We add to these variables four other control variables, two of which are related to bank's specific characteristics (bank size and leverage), and the two remaining are essentially related to the economic environment (i.e., gross domestic product rate and the subprime crisis). We then analyze the link between each variable and the Islamic banking efficiency. At the end of this analysis, we compare the efficiency of emerging countries Islamic banks to those in developed countries. Two levels of comparison are accordingly achieved: first, we compare banking efficiency in emerging countries to their counterparts in developed countries. Secondly, we compare the efficiency of banks from both regions before, during and after the crisis. The purpose of such a study is to fill the wide gap in the literature by providing empirical evidence on the influence of governance on the efficiency of Islamic banks in developed as well as developing countries between 2007 and 2017.

The major outcome of this article is that, relying on a multivariate data-mining model, the efficiency factor explained by governance-related regressors appears to be the factor enabling Islamic banks to withstand the most severe of global financial crises. Such a finding is supposed to offer investors alternative opportunities during global financial crises (Alqahtani et al., 2017; Belanès et al., 2015; Mirakhor, 2008; Olson & Zoubi, 2017; Rosman et al., 2014; Saâdaoui et al., 2017). Another significant contribution in this paper is to revisit the effect and the weight of some factors on the efficiency of Islamic banks based on effective nonparametric regression tools. This will allow new forms of efficiency to be achieved depending not only on the economic zone (developed or emerging), but also in times of crisis. The overall results support the idea that a virtuous governance improves the Islamic banking efficiency. It is noticeable that the experiments include the well-known "subprime" crisis ranging from 2007 to 2009. It also worth-noting that, in comparison with the list of previous works, the exploitation of a robust nonparametric technique like that of splines allows to refine the various estimates of the efficiency factor in this framework of Islamic finance. The results obtained are therefore supposed to be more precise than those got from econometric models. Such an accuracy is sufficient for operational decision makers to define high-level strategic indicators about Islamic banks' efficiency. The findings can also give bank managers, regulators, policymakers, and international bodies such as the Islamic Financial Services Board better insight into the performance of Islamic banks in developed and emerging countries during future financial crises.

This article is organized as follows. The theoretical framework and technical background are presented in Sect. 2 and Sect. 3, respectively. Section 4 presents the model's specification, while the empirical results are reported and discussed in Sect. 5. Finally, conclusions are drawn in Sect. 5.

2 Previous research

2.1 Modeling banks' efficiency

Banking efficiency is considered as one of the best indicators of financial success for Islamic banks. Previous studies have measured the efficiency of Islamic banks by overall technical efficiency, pure technical efficiency and efficiency of scale (Belanès et al., 2015; Rosman et al., 2014). Rosman et al. (2014), for instance, suggested that profitability and capitalization are the main determinants of Islamic banking efficiency. Bitar et al. (2017) examined the liquidity

ratio and the capital ratio as determinants of Islamic banking efficiency. They have shown that capital and liquidity positively relate to efficiency. Moreover, profitability can be also considered as a measure of Islamic banking efficiency as explained by Alqahtani et al. (2017). In other words, the most profitable banks tend to be more efficient. Several other researchers showed that the most liquid, profitable and capitalized banks are more efficient. Overall, the most examined efficiency indicators in recent literature are ROA and ROE (see Tamimi, 2010; Choong et al., 2012; Zeitun, 2012; Riaz & Mehar, 2013; Ongore and Kusa, 2013; Olson & Zoubi, 2017), but the main differences between these are the explanatory variables. Rashid and Jabeen (2016) examined banking performance through the Financial Performance Index (FPI) based on CAMELS ratios (Capital adequacy, Asset quality, Management, Earnings, Liquidity and Sensitivity to risk). They found that operational efficiency, deposits and market concentration are the main determinants of the performance of Islamic banks. In contrast, Zeitoun (2012) and Riaz and Mehar (2013), claimed that the size of the bank has a positive link with Islamic efficiency. This academic work has analyzed the financial efficiency of Islamic banks and neglected governance.

On the other hand, Islamic banking governance or Sharia governance is a social phenomenon in Islamic societies, which is based upon Koran and Sunna. The existence of Islamic governance shows that classical governance is not a law of nature but a social construction, as explained by Shibani and De Fuentes (2016). Islamic banks follow a governance, which respects the law of Muslims, guided by a Sharia board (Quttainah et al., 2013). The Islamic banking sector is not a homogenous group; full-fledged Islamic banks follow large and lax governance mechanisms, while their counterparts, Islamic window banks, guided by strong governance mechanisms, tend to invest more in human capital to increase their performance (Nawaz, 2019). The focus of Islamic governance is the Sharia board. This council monitors Islamic banking decisions, ensures their Sharia compliance (Choudhury & Alam, 2013), and avoids all unethical decisions that may influence Islamic banking performance (Al-Suhaibani & Naifar, 2014 and Mollah & Zaman, 2015). In addition, Shariah advisory strength improves profit efficiency (Safiullah & Shamsuddin, 2019) and improves the financial performance of Islamic banks (Farak et al., 2018; Mollah & Zaman, 2015). In addition, Bourakba (2014) suggested that there is a very strong relationship between governance variables and Islamic banking financial performance. In conclusion, recent literature shows that governance is a source of efficiency and financial performance. Thus, governance is a determinant of banking efficiency. Governance efficiency, as measured by the size of the board of directors, the board commissioner's size and the size of the sharia supervisory board, positively affects Islamic banking performance (Kusuma & Ayumardani, 2016). Moreover, governance, as measured by board size, CEO duality and agency cost in the GCC, has a significant effect on the financial and accounting performance of Islamic banks. Smaller boards are better able to closely monitor management, the dual role of CEOs is likely to improve bank performance, and the presence of blockholders in the ownership structure tends to have a positive effect on the performance of the Islamic banking sector (Naushad & Malik, 2015). Simultaneously, the recent literature is still focusing on the governance in the financial context and most findings in this direction confirm that efficiency represents one of the main sources of efficiency and performance (Bourakba, 2014; Mollah & Zaman, 2015; Farag et al., 2018 and Safiullah & Shamsuddin, 2019; Ngo et al., 2019; Nkuutu et al., 2020; Shahid et al., 2020). Governance is therefore a strong determinant of banking efficiency.

The size and independence of the board has a significant relationship with the profitability of Islamic banks. Ghaffar (2014) showed that the profitability of Islamic banks in Pakistan tends to increase with the adoption of good corporate governance practices. In addition, the study by Hamza (2013) showed that the independence of the Sharia board in their supervisory

role and the consistency of Sharia law are key elements of an effective Sharia governance structure. The presence of the Sharia board affects the return on equity and technical efficiency of the Islamic banking sector (Ur Rehman et al., 2010). According to Bourakba (2014), there is a very strong relationship between governance variables and the financial performance of Islamic banks. The composition of the board of directors, the size of the board of directors, the number of committees within the board, as well as the number of members of the Sharia Supervisory Board (SSB) show a very strong relationship with return on assets (ROA), but the ROA variable is negatively related to concentration ownership. Table 1 summarizes the most recent articles on Islamic banks' efficiency.

Table 1 Summary of articles on Islamic banks' efficiency

Authors	Year	Main control variable(s)	Method(s)
Rosman, R., Wahab, N.A., and Zainol, Z.,	2014	- Return on asset - Total assets - Equity/total asset - Loan loss provision/net interest revenue	DEA and Tobit
Belanès, A., Ftiti, Z., & Regaïeg, R	2015	- Crisis effect	DEA
Kusuma, H., & Ayumardani, A	2016	- Corporate governance efficiency - Total assets	DEA and panel data
Bitar, M., Hassan, M.K., and Walker, T	2017	- Political environment - Bank control variables - Macroeconomic variables	PCA and GLS
Alqahtani, F., Mayes, D.G., & Brown, K	2017	- Bank control variables - Macroeconomic control variables - Ownership and listing status	DEA, SFA, Tobit
Banna, H., Alam, M.R., Ahmad, R., and Sari, N.M	2020	- Financial inclusion factors	DEA and Simar-Wilson double bootstrapping regression
Ledhem, M.A., & Mekidiche, M	2020	- Economic growth	Dynamic panel approach
Nawaz, T., Haniffa, R., and Hudaib, M	2021	- Intellectual capital - Shariah governance variables - Governance-specific variables - Firm-specific control variables	Panel data
AlAbbad, A, Anantharaman, D, Govindaraj, S.,	2021	- Economic factors - Religious factors - political factors - Socio-legal factors	Panel data
Safiullah, M	2021	- Shariah board governance score - Bank-level control variables - Industry and country-level variables	Instrumental variables and dynamic panel

The majority of studies aiming to analyse the relationship between governance and Islamic banking efficiency or performance are based on simple estimation methods. Nevertheless, although proven very effective in several similar fields, data mining has been never used to analyse Islamic banking problems. Furthermore, as far as we know, data mining has rarely been applied in the banking sector. This approach can help to solve many banking problems by looking for patterns, associations and correlations hidden in the information stored in databases. Banks need to apply data mining to analyse customer's data. These customer's data are profiles, tastes and preferences, customer attitude and what is the customer's buying behaviour since the moment he/she is with the bank? (used for cross-selling products); transactions made by a customer before switching to a competitor (to avoid losing customers); products, often bought together by customers of a particular profile (for targeted marketing); trends in credit transactions that lead to fraud (to detect and deter fraud); the profile of a high-risk borrower (to avoid defaults, bad debts and improve screening); the services and benefits desirable by existing customers (to increase customer loyalty and retention) and customers who obtain all types of services from these banks (to identify "loyal" customers) (Bhambri, 2011).

2.2 Financial data-mining

Technically, data-mining is a set of advanced statistical techniques (classification, regression, segmentation, etc.) for exploring and analysing data in order to detect links, relationships, rules (depending on the subject matter) in the data to help us make the right decision (see Miyan, 2017; Peral et al., 2017). The choice between these techniques depends on the nature of the variable of interest. This method can be designed to analyse several financial and banking problems (Bhambri, 2011). Table 2 summarizes some of the problems that have been analysed using data mining approaches. It is noticeable that, in the banking sector, data mining has been commonly used to analyse the factors of the online e-banking phishing website and study its techniques (Aburrous et al., 2010) and to analyse customer confidence in e-banking (Liébana-Cabanillas et al., 2013).

These academic works suggested that this method is more advantageous compared with dashboards because it gives better results. According to these researchers, the data-mining method is ranked among the best recent approaches to data analysis. It gives efficient, clear, valuable and robust results. This method can analyse statistical data from several angles and perspectives by modelling, classifying and grouping a large amount of data, as well as discovering correlations between data. Based on the existing literature, several researchers have addressed the link between Islamic banking efficiency and governance. However, no study has analysed this issue using a data mining approach.

3 Multivariate adaptive regression splines (MARS)

Founded by Friedman (1991), the multivariate adaptive regression splines (MARS) model is a nonparametric data-mining algorithm for fitting the relationship between a set of exogenous variables and the dependent variable. This method can be seen as an extension of multivariate linear models that automatically models nonlinearities and interactions between variables. The principle is to generate basis functions by stepwise searching overall possible univariate candidate knots and across interactions among all variables. An adaptive regression algorithm is implemented for automatically selecting the knot locations.

Table 2 Summary of articles applying data mining in finance

Authors	Year	Problem
Lin, S-W., Shiu, Y-R., Chen, S-C., & Cheng, H-M.	2009	Applying enhanced data mining approaches in predicting bank performance
Aburrous, M., Hossain, M. A., Dahal, K., & Thabtah, F.	2010	Intelligent phishing detection system for e-banking using fuzzy data mining
Bhambri, V	2011	Application of data mining in banking sector
Liébana-Cabanillas, F., Noguera, R., Herrera, L. J., & Guillén, A.	2013	Analysing user trust in electronic banking using data mining methods
Soumya, S. B., & Deepika, N.	2016	Data mining with predictive analytics for financial applications
Miyan, M.	2017	Applications of data mining in banking sector
Peral, J., Maté, A., & Marco, M.	2017	Application of data mining techniques to identify relevant key performance indicators
Kaffash, S., Kazemi Matin, R. & Tajik, M.	2018	New semi-oriented radial measure (SORM) model to estimate the efficiency scores for a sample of banks
Yin, Z., Yu, Y., & Huang, J.	2018	Examining the bank efficiency using an approach that incorporates a non-concave metafrontier and undesirable outputs into a slack-based network DEA model
Cai, S., & Zhang, J.	2020	Exploration of credit risk of P2P platform based on data mining technology
Tahmasebi, R., Rostamy, A.A.A., Khorshidi, A., & Sharif, S.J.S.	2020	A data mining approach to predict companies' financial distress
Anouze, A.L., Bou-Hamad, I.	2021	DEA coupled with random forest to define the most influential environmental variables in the evaluation of bank performances

Let $X = (X_1, \dots, X_K)$ be a matrix of K input variables y be the dependent variable. Then it is assumed the data are generated based on an unknown “true” model. For a continuous response, this would be:

$$y = f(X) + e \quad (1)$$

where e is the fitting residual. f is the MARS's tendency formed by basis functions, which are piecewise spline polynomial functions. For instance, a piecewise linear-type function have the form of a hinge function, i.e., $\max(0, x - t)$ with a knot defined at t , which is defined as:

$$\max(0, x - t) = \begin{cases} x - t & \text{if } x \geq t \\ 0, & \text{otherwise} \end{cases} \quad (2)$$

The tendency component of the MARS model, which is a linear combination of basis functions and their interactions, can be expressed as follows:

$$f(X) = \alpha_0 + \sum_{i=1}^N \alpha_i \varphi_i(x) \quad (3)$$

where $\varphi_i(X)$, $i = 1, \dots, N$, are the N basis functions, and α_i 's are the parameters of the model estimated using a least-squares method. Each basis function takes one of the following two forms: (1) a hinge function, (2) a product of two or more hinge functions (for modeling interaction between two or more variables).

The MARS procedure works with forward/backward passes. The forward pass chooses entrant knots at random locations within the range of predictor variables to define a pair of basis functions. At each step, the model adapts the knot and its corresponding pair of basis functions to give the minimum mean square residuals (greedy search algorithm). This procedure continues until the maximum number is reached. The backward pass simply involves deleting the redundant basis functions of least contributions. It is notable that MARS models are more flexible than their linear counterparts are, are simple to understand and interpret, handle both continuous and categorical data, and often requires little or no data preparation. Concerning their implementations, several interface can be used for modeling data, such as Minitab, Statistica, Matlab/Octave (ARESLab toolbox, Jekabsons, 2011), R (earth package, Milborrow, 2019), etc. It also deserves to be noted that a number of promising extensions exist in the literature, the most prominent of which are Bayesian MARS by Denison et al. (1998) and MARS Time Series by Friedman (1991).

4 Model specification and data

4.1 Data sets

To test our hypotheses, we will use a sample composed of Islamic banks operating in developed economies (United Kingdom, Singapore, France, Germany) and Islamic banks operating in emerging economies (Egypt, Sudan, Mauritania, Tunisia, Iran, Malaysia). The period of our sample ranges year-by-year from 2007 to 2015. This period is known to include the well-known subprime crisis. All the following analysis is conducted using the MARS data-mining approach under Statistica³ software.

4.2 Choosing the appropriate method

The banking environment is often under the influence of major changes. To this end, numerous empirical studies have tried to analyse changes in bank efficiency. One of the indicators of banking performance in a competitive market is the measurement of efficiency. The latter can also help banks to identify the sources of their inefficiencies and formulate adequate strategies to improve their market situation. Efficiency studies can also be used to assess the impact of changes in market conditions and the impact of governance on banking efficiency. However, the measurement of bank efficiency has been determined by different approaches. These can be classified into two groups: ratio approaches, such as bank efficiency ratios, bank liquidity ratios and risk ratios. Econometric approaches are based on statistical models

³ <https://www.tibco.com>.

(which model banking efficiency), such as parametric and non-parametric approaches (which measure banking efficiency through statistical models based on determinants of financial efficiency) (Farrel, 1957). Twenty years later, two main approaches are competing in the way efficiency is measured and analysed: parametric and non-parametric approaches. In parametric approaches, the boundary is identified by an analytical function dependent on a finite number of parameters. The problem involves the specification of this function and the estimation of the parameters, either by methods derived from linear programming or by the statistical method of econometrics. Regarding non-parametric approaches, Taffé (1998) suggested that they could not specify an explicit analytical form for the boundary, but rather the formal properties that the production set is assumed to satisfy. The non-parametric approach results from the initial studies of Farrell (1957) and requires the use of linear programming techniques.

The choice between the two methods is difficult. According to Bosman and Frecher (1992) it is necessary to base oneself on one's knowledge of the technology of the sector under study. These authors argue that when one has clear information on what the underlying technology is, as in the case of the agricultural sector and manufacturing branches for example, the econometric estimation of parametric production frontiers is one-way. However, when it is a decision unit whose activity is the production of services, a non-parametric method seems more appropriate, since it is not based upon any explicit assumptions about technology and applies to activities with several "outputs" and several "inputs". Typically, banks focus on accounting ratios to estimate their efficiencies. Several ratios, such as return on assets (ROA) and return on equity (ROE), are used as indicators to analyse different aspects of financial and banking operations. Therefore, in our study we use data-mining to answer "efficiency-governance" issues. This method allows us to determine the governance variables that strongly influence Islamic banking efficiency and to predict the sources of efficiency and the sources of Islamic banking inefficiency. To answer this problem, it is necessary to identify the most relevant variables with the "Best Predictors" module. Then, the modeling of the variable of interest (efficiency) with the MARSpline algorithm.

Historically, the MARSplines method has been applied to study problems similar to banking problems. Chen et al. (2019) applied the MARS technique to create a comprehensive financial forecast of operating revenue, earnings per share, free cash flow and net working capital to help companies forecast their future financial position and provide investors and creditors a reference for making investment decisions. These authors have shown that this method improves financial forecasts. In addition, Kao et al. (2013) used the MARS to forecast stock market indices. Along the same lines, Manickavasagam et al. (2020) used the MARS to forecast oil prices. The results showed that the MARS model works better than other competitive models, and that the nonlinear model is the most suitable.

4.3 Variables definition

In this section, the main variables involved in the empirical model are presented. The dependent variable representing the banking efficiency is measured using two proxies: the ratio of non-performing loans to total loans (NPLTL) and the ratio of operating expenses to total assets (OETA). Five independent variables include four conventional measures of corporate governance: composition of the board of directors (CBD), size of board of directors (SBD), board committees (BC), concentration of ownership (COW) and an Islamic measure of governance: Sharia supervisory board (SSB). It is noticeable that the empirical model also includes four control variables; two control variables related to firm-specific characteristics (bank size

(BS) and leverage (LEV)) and two control variables related to the economic environment (gross domestic product growth rate (GDP) and the subprime crisis (CRISIS)). The list of variables and their abbreviations is as follows:

CBD: measured by percentage of independent members of the board;

SBD: measured by the percentage of managers in the council;

BC: measured by the percentage of committees in the board of directors;

COW: measured by: percentage of shares owned by major shareholders;

SSB: shariah supervisory board size;

IBS: size of Islamic bank: measured by logarithm of total assets;

LEV: measured by total assets to total equity;

GDP: gross domestic product growth rate (GDP);

CRISIS: a dummy variable for subprime crisis years, where the variable equals 1 if the period is within the crisis interval and 0 if it is outside of the crisis interval.

Our model is inspired by several published papers examining governance and banking efficiency issues within Islamic banks and their classic counterpart (see Bourakba, 2014; Adnan, 2011). Our study includes a sample of 43 Islamic banks operating in emerging and developed countries during the period 2007–2017, yielding 473 observations on the banking year. The data set is obtained from BankScope database.

5 Empirical results

We begin this section by interpreting the descriptive statistics and goodness-of-fit tests. Then, the results of the MARS modeling the relationship between banking efficiency and corporate governance variables will be discussed.

5.1 Preliminary statistical analysis

Table 3 shows the most important descriptive statistics for the variables used in the study. The average of NPLTL is estimated to 10.317 for developed countries, while it is 9.352 for emerging countries. The average OETA is 0.186 and 0.249 for developed and emerging countries, respectively. The average of composition of the board of director's variable (BCM) is 4.8 in developed countries and about 5.2 in emerging countries, which means that there is an acceptable number of independent members, which increases the independence and transparency of the council, then increases the effectiveness⁴ of corporate governance. The goodness-of-fit tests as well as shape statistics in Table 4 show that for the majority of variables, the distribution is different from that of a Gaussian. In Table 5, the correlations between the different variables show significant differences between the banking systems in developed and developing countries.

5.2 MARS implementation

MARSplines is a procedure for non-parametric regression available under Statistica software. As discussed above, MARS makes no assumptions about the underlying functional relationships between dependent and independent variables. The model rather constructs

⁴ Roghianian et al. (2012)

Table 3 Descriptive Statistics of the different variables of the models

	Minimal		Maximal		Mean		Std. Dev	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
<i>(a) CG variables</i>								
CBD	2	3	7	8	4.800	5.210	1.279	1.197
SBD	7	5	12	12	9	8.950	1.735	1.811
BC	1	2	5	6	2.867	3.213	1.091	1.127
COW	0.231	0.004	0.917	0.960	0.592	0.379	0.189	0.201
SSB	2	2	8	9	5.467	6.023	2.002	2.048
<i>(b) Efficiency variables</i>								
NPLTL	0.032	0.000	15.132	13.111	10.317	9.352	11.180	10.239
OETA	0.006	0.001	1.724	2.444	0.186	0.249	0.214	0.304
<i>(c) Control variables</i>								
IBS	13.626	12.944	18.907	18.181	16.148	15.911	1.384	1.094
LEV	0.460	0.053	6.336	24.860	2.081	2.592	1.281	2.221
GDP	- 5.619	- 7.076	7.425	19.592	2.654	4.346	2.709	4.086

(1) Developed countries, (2) Emerging countries

this relationship from a set of coefficients and basic functions that are directly derived from the data. In a way, the method is based on the "divide and conquer" methodology, which divides the input space into different regions, each with its own regression or classification equation. The MARSplines technique is therefore particularly well suited to deal with problems with many input dimensions (i.e. with more than two variables), where other techniques might fail because of too many dimensions.

Data: The MARS model is fed with data of Islamic banks from developed and emerging countries. The data represent five governance variables, including four conventional measures of corporate governance (the composition of the board of directors, the size of board of directors, board committees, concentration of ownership) and one Islamic measure of governance (size of the Sharia supervisory board). And four control variables; two control variables related to firm-specific characteristics (firm size and leverage) and two control variables related to the economic environment (i.e. the gross domestic product rate and the sub-prime crisis) between 2007 and 2017 (11 years) out of a selection of 15 Islamic banks operating in developed countries and 38 Islamic banks operating in emerging countries.

Issue: The objective of this study is to analyse the impact of governance on Islamic banking efficiency, i.e. the analysis of variables that influence the efficiency of Islamic banks in two regions with different levels of development. We will therefore treat the efficiency variable (i.e. the performance measured by two proxies; i.e. ratio of non-performing loans to total loans (NPLTL) and ratio of operating expenses to total assets (OETA) as dependent (or response) variables, and all other variables as independent (or predictor) variables. We therefore have 9 independent variables (CBD, SBD, BC, COW, SSB, IBS, LEV, GDP and CRISIS) and 1 dependent variable (Islamic banking efficiency measured by two proxies (the ratio of non-performing loans to total loans (NPLTL) and the ratio of operating expenses to total assets (OETA)).

Table 4 Goodness-of-fit tests for the different variables used in the models

	CBD	SBD	BC	COW	SSB	NPLTL	OETA	IBS	LEV	GDP
<i>Developed countries</i>										
Skewness	0.2660	0.4149	- 0.2005	- 0.2371	- 0.2026	1.6129	4.1943	- 0.1348	1.3946	- 0.5016
Kurtosis	2.0434	1.7508	3.0770	2.3605	1.9898	8.2280	25.9759	2.0354	4.4346	3.1918
JB test	0.0232	0.0055	0.5000	0.0829	0.0238	0.0000	0.0000	0.0334	0.0000	0.0310
KS test	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
<i>Emerging countries</i>										
Skewness	0.4597	- 0.0100	0.0514	0.1140	- 0.3308	7.8471	3.8407	- 3.9902	4.6235	1.2659
Kurtosis	2.2172	2.4472	2.5074	1.8795	1.9151	83.0939	23.7162	48.1647	38.3079	6.8912
JB test	0.0000	0.0619	0.0942	0.0010	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
KS test	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

JB test and KS test stand for Jarque-Bera and Kolmogorov-Smirnov tests, respectively

Table 5 Correlations between the different variables used in the models

	CBD	SBD	BC	COW	SSB	NPLTL	OETA	IBS	LEV	GDP
<i>Developed countries</i>										
CBD	1.0000	0.3255	0.7019	0.2484	0.0901	0.1387	0.4231	0.1410	0.3821	-0.0267
SBD	0.3255	1.0000	0.5110	0.0521	0.3670	0.4057	0.3439	-0.3158	0.3486	0.0190
BC	0.7019	0.5110	1.0000	0.1737	0.1938	0.1837	0.4536	-0.0989	0.2259	0.0009
COW	0.2484	0.0521	0.1737	1.0000	0.0345	0.1872	-0.0266	0.1689	0.2674	0.2509
SSB	0.0901	0.3670	0.1938	0.0345	1.0000	0.1224	-0.0242	0.1534	-0.1937	0.0222
NPLTL	0.1387	0.4057	0.1837	0.1872	0.1224	1.0000	0.0206	0.0274	0.1604	0.3459
OETA	0.4231	0.3439	0.4536	-0.0266	-0.0242	0.0206	1.0000	-0.2100	0.3896	-0.1970
IBS	0.1410	-0.3158	-0.0989	0.1689	0.1534	0.0274	-0.2100	1.0000	-0.1052	0.1666
LEV	0.3821	0.3486	0.2259	0.2674	-0.1937	0.1604	0.3896	-0.1052	1.0000	-0.0625
GDP	-0.0267	0.0190	0.0009	0.2509	0.0222	0.3459	-0.1970	0.1666	-0.0625	1.0000
<i>Emerging countries</i>										
CBD	1.0000	0.1321	0.5336	-0.0064	0.3746	-0.1657	0.1123	0.1095	-0.0794	-0.0373
SBD	0.1321	1.0000	0.1531	0.2143	-0.1419	-0.1137	-0.1066	-0.0068	-0.1809	-0.0391
BC	0.5336	0.1531	1.0000	0.0162	-0.0453	-0.0785	0.0847	0.0361	-0.1460	-0.0163
COW	-0.0064	0.2143	0.0162	1.0000	0.0337	-0.0897	-0.1697	-0.1667	0.1434	0.2447
SSB	0.3746	-0.1419	-0.0453	0.0337	1.0000	-0.2032	0.1073	-0.0834	0.1217	-0.0756
NPLTL	-0.1657	-0.1137	-0.0785	-0.0897	-0.2032	1.0000	-0.0561	0.0740	0.4139	0.2172
OETA	0.1123	-0.1066	0.0847	-0.1697	0.1073	-0.0561	1.0000	-0.0263	-0.0941	-0.1468
IBS	0.1095	-0.0068	0.0361	-0.1667	-0.0834	0.0740	-0.0263	1.0000	-0.2197	-0.0876
LEV	-0.0794	-0.1809	-0.1460	0.1434	0.1217	0.4139	-0.0941	-0.2197	1.0000	0.1944
GDP	-0.0373	-0.0391	-0.0163	0.2447	-0.0756	0.2172	-0.1468	-0.0876	0.1944	1.0000

The abbreviations of the variables are as in Sect. 4.3

5.3 MARS results

Banking efficiency is a very broad notion, which includes several dimensions, namely "informational efficiency" of the banking system, i.e., the effectiveness of banks in controlling borrowers, and "organizational efficiency" which is also closely linked to the structure of the banking market (Eber, 2000). There is also financial efficiency measured by different accounting ratios, measured also by overall technical efficiency, pure technical efficiency and efficiency of scale (Rosman et al., 2014). In this section, we study the effects of governance on the efficiency of Islamic banks in developed/developing countries. For this aim, we rely on the Statistica's MARS regression to analyse the relationship of each variable with the efficiency of these banks. In other words, a parsimonious non-parametric model is used to analyse the importance of a number of regressors on the Islamic banking efficiency. We therefore limit ourselves to a very narrow definition of efficiency; in this case, which is the Islamic banking efficiency based on governance. This means that we will not deal with other aspects of Islamic banking efficiency.

5.3.1 Model 1: OETA-measured efficiency in emerging countries

First, we rely on the OETA variable to measure the Islamic banking efficiency. Our first test, essentially focusing on Islamic banks in emerging countries shows several important findings. The MARS regression involves one dependent variable (y) and nine independent variables ($X_{n,9}$). The order of interaction is set to three, the penalty is two, and the convergence threshold is fixed to 0.0005. The application of the "pruning" option of MARSpline gives us the following model specifications: number of terms: 15; number of basis functions: 31; and generalized cross-validation (GCV) error equal to 0.063. We begin with the analysis of the data sheet on the importance of the predictors (see references to basis functions (RBF) in Table 6). We find that the variable SBD has one in the FBF line, i.e., this variable is used in only one basis function. This means that this variable is relatively important in this model. We also observe that the variable LEV is used in three basic functions, while the variable IBS is used in four functions.

The regressor GDP is used in five basic functions, while CBD is used in seven basis functions. These variables are therefore important in this model. In addition, the variable COW is used in eleven basic functions, therefore, this variable is very important in this model. On the other hand, the variables SSB, CRISIS and BC have a zero in the reference line. We can therefore conclude that these variables are not used in any basis function and are not important in our first model. Based on these results, it can be seen that the strong sources of efficiency for this group of banks are COW, CBD (Bourakba, 2014), GDP and IBS (Adnan et al., 2011). The MARS will construct the regression function using the weighted sums of the terms integrating the products of the basis functions. The coefficients reported in Table 6 provide all information about the model's terms and the corresponding coefficients. It also informs about the type of each basis function and the order of interactions in each term. In the model, the term corresponding to the intercept is equal to 0.317. It is notable that the coefficients with asterisks in the next tables indicate basis functions of type $\max(0, \text{independent-knot})$, otherwise $\max(0, \text{knot-independent})$. Model 1 can be summarized as in Eq. (4).

Table 6 Coefficients of the OETA—based model to measure Islamic banking efficiency in emerging countries

Basis Function	Coefficients OETA	Knots IBS	Knots LEV	Knots SSB	Knots CRISIS	Knots CBD	Knots BC	Knots COW	Knots SBD	Knots GDP
RBF		4	3	0	0	7	0	11	1	5
Intercept	0.3169	—	—	—	—	—	—	—	—	—
Term 1	− 0.8650	—	—	—	—	—	—	0.1935*	—	—
Term 2	0.6359	—	—	—	—	2.000*	—	0.1935*	—	—
Term 3	− 0.11679	15.170*	—	—	—	2.000*	—	0.1935*	—	—
Term 4	0.3985	15.170	—	—	—	2.000*	—	0.1935*	—	—
Term 5	0.6482	—	1.445	—	—	2.000*	—	0.1935*	—	—
Term 6	1.2700	—	—	—	—	—	—	0.5094*	—	—
Term 7	− 6.2500	16.260*	—	—	—	—	—	0.1935	—	—
Term 8	− 3.4840	16.260	—	—	—	—	—	0.1935	—	—
Term 9	− 0.04938	—	—	—	—	2.000*	—	0.1935*	—	7.088*
Term 10	− 0.08329	—	—	—	—	2.000*	—	0.1935*	—	7.088
Term 11	0.04032	—	—	—	—	—	—	—	—	6.245
Term 12	− 0.06853	—	—	—	—	2.000*	—	0.1935*	0.1935*	—
Term 13	− 0.01094	—	2.7889*	—	—	—	—	—	—	6.245
Term 14	− 0.01578	—	2.7889	—	—	—	—	—	—	6.245

Asterisks indicate basis functions of type max(0, independent − knot), otherwise max(0, knot − independent). RBF stands for references to basis functions, which is the number of times each predictor is referenced in the model

$$\begin{aligned}
\text{Efficiency} = & 3.169 - 8.650 \max(0; \text{COW} - 1.935) + 6.359 \\
& \times \max(0; \text{CBD} - 2.000) \max(0; \text{COW} - 1.935) - 1.679 \\
& \times \max(0; \text{IBS} - 1.517) \max(0; \text{CBD} - 2.000) \times \max(0; \text{COW} - 1.935) \\
& + 3.985 \max(0; 1.517 - \text{IBS}) \times \max(0; \text{CBD} - 2.000) \max(0; \text{COW} - 1.935) \\
& + 6.482 \times \max(0; 1.445 - \text{LEV}) \max(0; \text{CBD} - 2.000) \times \max(0; \text{COW} - 1.935) \\
& + 1.270 \max(0; \text{COW} - 5.094) - 6.250 \times \max(0; \text{IBS} - 1.626) \max(0; 1.935 - \text{COW}) \\
& - 3.484 \times \max(0; 1.626 - \text{IBS}) \max(0; 1.935 - \text{COW}) - 4.938 \\
& \times \max(0; \text{CBD} - 2.000) \max(0; \text{CON} - 1.935) \\
& \times \max(0; \text{GDP} - 7.088) - 8.329 \max(0; \text{CBD} - 2.000) \\
& \times \max(0; \text{COW} - 1.935) \max(0; 7.088 - \text{GDP}) + 4.032 \times \max(0; 6.245 - \text{GDP}) \\
& - 6.853 \max(0; \text{CBD} - 2.000) \times \max(0; \text{COW} - 1.935) \max(0; \text{SBD} - 5.000) \\
& - 1.094 \times \max(0; \text{LEV} - 2.789) \max(0; 6.245 - \text{GDP}) - 1.578 \\
& \times \max(0; 2.789 - \text{LEV}) \max(0; 6.245 - \text{GDP}) \tag{4}
\end{aligned}$$

The value of the coefficient of determination R^2 in this first model is about 0.89, which means that 89% of the variations in the endogenous variable are explained by the model. The results show that the variables IBS and COW have a significant negative effect on the efficiency of Islamic banks in emerging countries at a level of 1%. Moreover, the variables SBD, LEV and GDP have a significant negative effect on the efficiency of these banks at the level of 5%. The model is globally significant at the 1% level, with a Fisher statistic $F(9,407) = 4.4449$.

5.3.2 Model 2: NPLTL-measured efficiency in emerging countries

We now use the variable NPLTL as a measure of Islamic banking efficiency. The results of this second model shows several noteworthy results (Table 7). The same multiparameters as used in the last model are preliminarily fixed. In the current model, we can note in the data sheet that the variables SSB and BCM have two as RBF. This implies that these variables are used in two basic functions, which means that these regressors are relatively important in this model. We also observe that the variable IBS is used in four basic functions and the variable LEV in six basic functions, which means that these variables are important in this model. In addition, the GDP variable is used in nine basic functions and COW in eleven basis functions, therefore, these variables are of great important in the model. On the other hand, the variables SSB, CRISIS, BC and SBD have a zero in the reference column. We can therefore conclude that these variables are not used in any basic function and that they are not important in the second model. These results show that the variables COW (Bourakba, 2014), GDP, LEV and IBS (Adnan et al., 2011) are strong sources of efficiency for this sample of Islamic banks. MARS constructs the model using the weighted sums of the terms integrating the products of the basis functions. The coefficients in Table 7 provide all information about the model.

Model 2 can be written as in Eq. (5). The coefficient R^2 is about 0.82. The results show that the variables SIZE, LEV and GDP have a positive effect on the efficiency of Islamic banks in emerging countries at a significance level of 1%. On the other hand, the variables SSB and COW have a negative effect on the efficiency at a significance level of 1%. Moreover, the variable CBD has a negative effect on the efficiency but with a significance of only 10%. Despite this, the model remains overall significant at 1%.

Table 7 Coefficients of the NPLTL—based model to measure Islamic banking efficiency in emerging countries

Basis Function	Coefficients OETA	Knots IBS	Knots LEV	Knots SSB	Knots CRISIS	Knots CBD	Knots BC	Knots COW	Knots SBD	Knots GDP
RBF		4	6	2	0	2	0	11	0	9
Intercept	0.3015	—	—	—	—	—	—	—	—	—
Term 1	−0.0191	—	4.244	—	—	—	—	—	—	—
Term 2	0.0646	16.200	4.244*	—	—	—	—	—	—	—
Term 3	0.02052	16.200*	4.244*	—	—	—	—	—	—	−7.076*
Term 4	0.2077	—	—	—	—	—	—	0.3460*	—	—
Term 5	0.6855	—	—	—	—	—	—	0.3460	—	—
Term 6	5.219	17.370*	—	—	—	—	—	0.3460*	—	—
Term 7	−0.1396	17.370	—	—	—	—	—	0.3460*	—	—
Term 8	0.01722	—	4.244*	—	—	—	—	—	—	9.249*
Term 9	0.3811	—	—	—	—	—	—	0.3460*	—	7.088*
Term 10	−0.1199	—	4.177*	—	—	—	—	0.3460*	—	7.088*
Term 11	−0.1133	—	4.177	—	—	—	—	0.3460*	—	7.088*
Term 12	−0.2177	—	—	4.000*	—	—	—	0.3460*	—	7.088*
Term 13	−0.2985	—	—	4.000	—	—	—	0.3460*	—	7.088*
Term 14	0.2963	—	—	—	—	3.000*	—	0.3460*	—	7.088*
Term 15	0.3246	—	—	—	—	3.000	—	0.3460*	—	7.088*

Asterisks indicate basis functions of type max(0, independent − knot), otherwise max(0, knot − independent). RBF stands for references to basis functions, which is the number of times each predictor is referenced in the model

$$\begin{aligned}
\text{Efficiency} = & 3.015 - 1.914 \max(0; 4.244 - \text{LEV}) + 6.460 \times \max(0; 1.620 - \text{IBS}) \max(0; \text{LEV} - 4.244) \\
& + 2.052 \times \max(0; \text{IBS} - 1.620) \max(0; \text{LEV} - 4.244) \times \max(0; \text{GDP} - 7.076) \\
& + 2.077 \max(0; \text{COW} - 3.460) + 6.855 \times \max(0; 3.460 - \text{COW}) \\
& + 5.219 \max(0; \text{IBS} - 1.737) \times \max(0; \text{COW} - 3.460) \\
& - 1.396 \max(0; 1.737 - \text{IBS}) \times \max(0; \text{COW} - 3.460) + 1.722 \max(0; \text{LEV} - 4.244) \\
& \times \max(0; \text{GDP} - 9.249) + 3.811 \max(0; \text{COW} - 3.460) \times \max(0; \text{GDP} - 7.088) \\
& - 1.199 \max(0; \text{LEV} - 4.177) \times \max(0; \text{COW} - 3.460) \max(0; \text{GDP} - 7.088) - 1.133 \\
& \times \max(0; 4.177 - \text{LEV}) \max(0; \text{COW} - 3.460) \times \max(0; \text{GDP} - 7.088) \\
& - 2.177 \max(0; \text{SSB} - 4.000) \times \max(0; \text{COW} - 3.460) \max(0; \text{GDP} - 7.088) - 2.985 \\
& \times \max(0; 4.000 - \text{SSB}) \max(0; \text{COW} - 3.460) \times \max(0; \text{GDP} - 7.088) \\
& + 2.963 \max(0; \text{CBD} - 3.000) \times \max(0; \text{COW} - 3.460) \max(0; \text{GDP} - 7.088) \\
& + 3.246 \times \max(0; 3, 000 - \text{CBD}) \max(0; \text{COW} - 3.460) \times \max(0; \text{GDP} - 7.088) \quad (5)
\end{aligned}$$

5.3.3 Model 3: OETA-measured efficiency in developed countries

We now rely on the OETA's performance to measure banking efficiency. The same exogenous variables are used as regressor inputs. In this problem dealing with Islamic banks in developed countries, the results shows different suggestions. As reported in Table 8, the variables IBS, CRISIS and COW have one as RBF. We can conclude that these variables are used in a single basis function, which means that these variables are relatively important in this model. The variable LEV has two in the reference column, while the variable GDP has three. Accordingly, these variables are relatively more important than the variables IBS, CRISIS and COW. We also observe that the variables SSB and BC are used in six basic functions, which proves that these variables are very important in the model. On the other hand, the variables CBD and SBD have zero as references. Therefore, these variables are not used in any basis function. These results show that the efficiency of this sample of banks is strongly related to SSB and BC variables (Bourakba, 2014). The results of the MARS estimation for model 3 are given in Eq. (6).

For model 3, the coefficient of determination R^2 is about 0.76, which means that 76% of the variation in the outcome variable is explained by the model. The results show that the variables LEV and BC have a significant positive effect on the efficiency of Islamic banks in developed countries at a level of 1%. The GDP variable has a significant negative effect on the efficiency of these banks at a level of 5%. The CBD variable has a positive effect on efficiency but at a significance level of 10%, while the variable COW has a negative effect at the same significance level. The model is overall significant at 1%.

$$\begin{aligned}
\text{Efficiency} = & 2.008 - 9.872 \max(0; \text{BC} - 6.000) - 5.232 \max(0; 6.000 - \text{BC}) \\
& + 6.085 \max(0; \text{SSB} - 2.000) \max(0; \text{BC} - 6.000) - 1.415 \times \max(0; \text{SSB} - 2.000) \max(0; \text{CRISIS} - 0.321) \\
& \times \max(0; \text{BC} - 6.000) - 5.286 \max(0; \text{SSB} - 2.000) \times \max(0; \text{BC} - 6.000) \max(0; \text{COW} - 2.308) \\
& + 2.867 \times \max(0; 5.000 - \text{SSB}) + 6.051 \max(0; \text{IBS} - 1.659) \times \max(0; \text{SSB} - 2.000) \max(0; \text{BC} - 6.000) \\
& + 1.713 \times \max(0; \text{LEV} - 2.853) \max(0; 1.953 - \text{GDP}) + 5.708 \times \max(0; 2.853 - \text{LEV}) \max(0; 1.953 - \text{GDP}) \\
& - 2.591 \times \max(0; \text{SSB} - 5.000) \max(0; 1.082 - \text{GDP}) \quad (6)
\end{aligned}$$

Table 8 Coefficients of the OETA—based model to measure Islamic banking efficiency in developed countries

basis function	Coefficients OETA	Knots IBS	Knots LEV	Knots SSB	Knots CRISIS	Knots CBD	Knots BC	Knots COW	Knots SBD	Knots GDP
RBF		1	2	6	1	0	6	1	0	3
Intercept	0.2008	—	—	—	—	—	—	—	—	—
Term 1	− 0.9872	—	—	—	—	—	6.000*	—	—	—
Term 2	− 0.05232	—	—	—	—	—	6.000	—	—	—
Term 3	0.6085	—	—	2.000*	—	—	6.000*	—	—	—
Term 4	− 0.1415	—	—	2.000*	0.3212*	—	6.000*	—	—	—
Term 5	− 0.5286	—	—	2.000*	—	—	6.000*	0.2308*	—	—
Term 6	0.02867	—	—	5.000	—	—	—	—	—	—
Term 7	0.6051	16.590*	—	2.000*	—	—	6.000*	—	—	—
Term 8	0.1713	—	2.853*	—	—	—	—	—	—	0.1953
Term 9	0.05708	—	2.853	—	—	—	—	—	—	0.1953
Term 10	− 0.02591	—	—	5.000*	—	—	—	—	—	1.082

Asterisks indicate basis functions of type max(0, independent− knot), otherwise max(0, knot− independent). RBF stands for references to basis functions, which is the number of times each predictor is referenced in the model

5.3.4 Model 4: NPLTL-measured efficiency in developed countries

In the last model, we use the performance based on the NPLTL to measure Islamic banking efficiency in developed countries. The results of the model identification are reported Table 9). As for the case of the three above-estimated models, the MARS algorithm is run with one dependent variable and nine independent variables. The order of interaction is fixed to three, the penalty to two, and the convergence threshold to 0.0005. The application of pruning in this model leads to the following specifications: number of terms 14, number of basis functions 29, and CVG error equal to 0.003. Table 9 reports the importance of the predictors. The variables CRISIS, LEV, CBD and IBS have one, two, two, and three respectively. We can conclude that these variables are relatively important in this model. The variables SSB, BC and SDB have five, seven and nine as references, respectively, which proves their position in this model. On the other hand, the variables COW and GDP have zero in the reference column. The MARS results are given in Table 9 and summarized in Eq. (4). The term corresponding to the intercept is 0.337. The first term consists of the base function (SSB—5.000). The fifth term is the product of (BC—5.000) and (SBD—7.000). The seventh term consists of the basic function (15.955—IBS), (5.000—SSB) and (SBD—7.000). In the fourth model, the value of R^2 is 0.81. The results show that the regressors SBD and GDP positively explain the efficiency of Islamic banks in developed countries at $\alpha = 1\%$. The two variables COW and IBS have positive effects on the efficiency at the levels 5% and 10%, respectively. In addition, the two variables SSB and CBD have a significant negative effect on the efficiency at the level of 5% and 10% respectively. The model is overall significant at $\alpha = 1\%$.

$$\begin{aligned}
 \text{Efficiency} = & 3.369 - 4.336 \max(0; \text{SSB} - 5.000) - 1.793 \times \max(0; 5.000 - \text{SSB}) \\
 & + 9.338 \max(0; 1.596 - \text{IBS}) \times \max(0; 5.000 - \text{SSB}) + 2.870 \max(0; \text{SBD} - 7.000) \\
 & - 9.543 \times \max(0; \text{BC} - 5.000) \max(0; \text{SBD} - 7.000) + 1.489 \\
 & \times \max(0; 5.000 - \text{BC}) \max(0; \text{SBD} - 7.000) \\
 & - 2.799 \times \max(0; 1.596 - \text{IBS}) \max(0; 5.000 - \text{SSB}) \\
 & \times \max(0; \text{SBD} - 7.000) - 8.215 \max(0; \text{CRISIS} - 0.648) \\
 & \times \max(0; 5.000 - \text{BC}) \max(0; \text{SBD} - 7.000) - 2.827 \\
 & \times \max(0; \text{LEV} - 3.501) \max(0; 5.000 - \text{BC}) \\
 & \times \max(0; \text{SBD} - 7.000) + 3.476 \max(0; 3.501 - \text{LEV}) \\
 & \times \max(0; 5.000 - \text{BC}) \max(0; \text{SBD} - 7.000) \\
 & + 7.248 \times \max(0; 1.541 - \text{IBS}) \max(0; 5.000 - \text{BC}) \\
 & \times \max(0; \text{SBD} - 7.000) - 1.481 \max(0; \text{CBD} - 1.000) \\
 & \times \max(0; 5.000 - \text{BC}) \max(0; \text{SBD} - 7.000) + 5.785 \\
 & \times \max(0; 5.000 - \text{SSB}) \max(0; \text{CBD} - 1.000)
 \end{aligned} \tag{6}$$

5.3.5 Discussion

The last part of our analysis is a recapitulative one. The MARS's efficiency predictions over the crisis and non-crisis periods in developed and emerging countries are reported in Table 10. We first focus on the efficiency measured by the OETA ratio. As estimated in the last subsections, the efficiency of Islamic banks in emerging countries is mainly explained by the variables COW and CBD, while the efficiency of their counterparts in developed countries is mainly based on variables SSB and BC. The overall efficiency score for banks in emerging

Table 9 Coefficients of the NPLTL—based model to measure Islamic banking efficiency in developed countries

Basis function	Coefficients NPLTL	Knots IBS	Knots LEV	Knots SSB	Knots CRISIS	Knots CBD	Knots BC	Knots COW	Knots SBD	Knots GDP
RBF		3	2	5	1	2	7	0	9	0
Intercept	0.3369	—	—	—	—	—	—	—	—	—
Term 1	-0.04336	—	—	5.000*	—	—	—	—	—	—
Term 2	-0.1793	—	—	5.000	—	—	—	—	—	—
Term 3	0.09338	15.960	—	5.000	—	—	—	—	—	—
Term 4	0.02870	—	—	—	—	—	—	—	7.000*	—
Term 5	-0.009543	—	—	—	—	—	5.000*	—	7.000*	—
Term 6	0.1489	—	—	—	—	—	5.000	—	7.000*	—
Term 7	-0.2799	15.960	—	5.000	—	—	—	—	7.000*	—
Term 8	-0.08215	—	—	—	0.648*	—	5.000	—	7.000*	—
Term 9	-0.02827	—	3.501*	—	—	—	5.000	—	7.000*	—
Term 10	0.03476	—	3.501	—	—	—	5.000	—	7.000*	—
Term 11	0.07248	15.410	—	—	—	—	5.000	—	7.000*	—
Term 12	-0.1481	—	—	—	—	1.000*	5.000	—	7.000*	—
Term 13	0.05785	—	—	5.000	—	1.000*	—	—	—	—

Asterisks indicate basis functions of type max(0, independent - knot), otherwise max(0, knot - independent). RBF stands for references to basis functions, which is the number of times each predictor is referenced in the model

Table 10 MARS prediction of efficiency measures for Islamic banks in the two regions

Year	OETA		NPLTL	
	Emerg. countries	Dev. countries	Emerg. countries	Dev. countries
2007	0.55	0.64	0.50	0.60
2008	0.55	0.65	0.50	0.65
2009	0.59	0.67	0.59	0.69
Mean (crisis period)	0.56	0.65	0.53	0.65
2010	0.55	0.69	0.54	0.68
2011	0.53	0.71	0.56	0.68
2012	0.53	0.70	0.53	0.73
2013	0.54	0.72	0.52	0.73
2014	0.56	0.72	0.53	0.72
2015	0.55	0.74	0.52	0.74
2016	0.54	0.79	0.53	0.75
2017	0.54	0.79	0.65	0.76
Mean (non-crisis period)	0.54	0.73	0.55	0.72
Mean (Overall)	0.55	0.71	0.54	0.70

OETA and NPLTL stand for operating expenses to total assets and non-performing loans to total loans, respectively

countries is of 55% compared with a score of 71% for Islamic banks in developed countries. We can also note that, over the two periods of crisis and non-crisis, the efficiency proportions do not vary significantly, especially in emerging countries. In other words, in emerging countries, the subprime crisis did not have serious repercussions on the Islamic banking systems. Despite this, we can conclude that banks in developed countries are somewhat more efficient than those in emerging countries. If we focus on the NPLTL ratio instead, we will notice that the results are a little different. Indeed, the MARS regression results conducted above showed that the efficiency of Islamic banks in emerging countries is explained by the variables LEV, GDP and COW, while in developed countries it is rather explained by the variables SSB, BC and SBD. The statistics of Table 10 show an efficiency score of 54% for banks in emerging countries compared to a score of 70% for Islamic banks in developed countries. In fact, several factors could explain this difference, such as the improvement in the quality of institutions and the development in developed country governance, which enhances the effectiveness of banks and then promotes economic growth. Moreover, as in the case where OETA is used as an efficiency proxy, the subprime financial crisis did not significantly change the efficiency levels for emerging countries. We can therefore deduce that the crisis did not have a detrimental effect on this type of banks, at least compared with their conventional counterparts. This result somewhat confirms the findings of Belanès et al. (2015) who had already proved that, during the same crisis, most Islamic banks have remained efficient. Overall, based on the two efficiency measures, we can say by intuition that the subprime crisis has no effect on Islamic banks in emerging countries but has a weak effect on the efficiency of Islamic banks in developed countries. However, this hypothesis needs to be addressed in greater depth in future works. Finally, we note that during or after the crisis, the average efficiency levels based on the NPLTL ratio confirms those based on

OETA, proving, in fact, that banks in developed countries are more efficient than banks in emerging countries.

In future work, it would also be insightful to extend the MARS algorithm in order to create a parallel computation procedure with better characteristics, especially in terms of convergence. In the literature, some works such as Bakin et al. (2000) had already attempted such directions. Using the MARS approach developed using B-splines for this problem of Islamic finance as well as the comparison with the present results in the basis of prediction experiments is also a promising avenue to explore (as in Richardson et al., 2008). Preliminary adjustment of the more turbulent factors on multiresolution subspaces is also a preprocessing, which is supposed to give more flexibility and robustness to the MARS model. This kind of preprocessing had already proven its value for Islamic finance data over periods of crisis (see the work of Saâdaoui et al., 2017). A coupling between MARS and another ML approach such as deep neural networks is also one of the potential concepts to be tested on our data. However, any such coupling should also undergo an evaluation step on the basis of its machine processing cost. Contagion risks in the banking system in relationship with international crises is a subject that can also be of great interest, in particular in a context of pandemics such as corona-virus. The role that good governance of Islamic banks can play is not only preserving efficiency, sovereignty and financial equilibrium, but also creating a reliable alternative to the conventional banking system (Huynh et al., 2020; Saâdaoui 2018; Saâdaoui et al., 2017).

6 Conclusion

Islamic banking efficiency is an important indicator for understanding how factors, such as governance, competition, market concentration and market power, affect credit and deposit markets, along with their impacts on interest rate margins. In this paper, a data-mining approach is performed for estimating the governance-based efficiency of Islamic banks in developed and emerging countries. A year-by-year sample spanning the period encompassing the subprime crisis is studied. The preliminary statistical tests revealed some non-standard and non-linear properties. The MARS data-mining tool provides a parsimonious model capable of capturing the various forms of non-linearity in the data. Accordingly, the estimated model better reflects the geometry of the analyzed data, thus leading to less biased predictions than those obtained from a classical econometric model such as that used in the majority of literature papers. Measuring the efficiency via the OETA variable has shown that the Islamic banks efficiency within emerging countries is mainly based upon CBD, COW and GDP, while those of the developed countries are rather based upon SSB and BC. Alternatively, measuring efficiency via NPLTL has shown that, in emerging countries, COW, GDP and LEV significantly explain banks efficiency, unlike those of developed countries that are explained rather by SBD, BC and SSB. It is also notable that governance is proven the main factor in Islamic banks in both regions. At the end of this study, other notable results deserve to be highlighted. For instance, the OETA-based overall efficiency ratio is 55% for emerging countries' Islamic banks opposed to 71% for developed countries' Islamic banks. As for the NPLTL-based overall efficiency ratio, it is about 54% for emerging countries' Islamic banks and 70% for developed countries' Islamic banks. Accordingly, and based on the two scores, it is evident that developed countries' Islamic banks are more efficient than their counterparts in emerging countries. It is also worth noting that the subprime crisis had no significant effect on emerging countries' Islamic banks, while it was relatively weak for developed countries' Islamic banks. These results provide a significant contribution as their

findings can give bank operational managers, regulators, policymakers, and international bodies such as the Islamic Financial Services Board better insight into the performance of Islamic banks in developed and emerging countries during future financial crises. This can be in the context of a pandemic such as COVID-19. Therefore, we think that a similar study under the circumstances of the pandemic is worth conducting. In fact, it would be important to evaluate the reaction and especially the power of the Islamic banking system to counteract the strong tremors experienced by the world economy the two last years, especially in comparison with the scenario of the subprime crisis. This remains an open question, which may not have a generalizable answer, but an answer that depends on a particular socio-political context.

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References

- Abduh, M., Hasan, S., & Pananjung, A. (2013). Efficiency and performance of Islamic Banks in Bangladesh. *Journal of Islamic Banking and Finance*, *30*(2), 94–106.
- Abdul-Majid, M., Saal, D. S., & Battisti, G. (2010). Efficiency in Islamic and conventional banking: An international comparison. *Journal of Productivity Analysis*, *34*(1), 25–43. <https://doi.org/10.1007/s11123-009-0165-3>
- Aburroum, M., Hossain, M. A., Dahal, K., & Thabtah, F. (2010). Intelligent phishing detection system for e-banking using fuzzy data mining. *Expert Systems with Applications*, *37*(12), 7913–7921.
- Adnan, M. A., Htay, S. N. N., Rashid, H. M. A., & Meera, A. K. M. (2011). A panel data analysis on the relationship between corporate governance and bank efficiency. *Journal of Accounting, Finance and Economics*, *1*(1), 1–16.
- Affes, Z., & Hentati-Kaffel, R. (2019). Forecast bankruptcy using a blend of clustering and MARS model: Case of US banks. *Annals of Operations Research*, *281*, 27–64. <https://doi.org/10.1007/s10479-018-2845-8>
- Alqahtani, F., Mayes, D. G., & Brown, K. (2017). Islamic bank efficiency compared to conventional banks during the global crisis in the GCC region. *Journal of International Financial Markets, Institutions and Money*, *51*, 58–74.
- Al-Suhaibani, M., & Naifar, N. (2014). Islamic corporate governance: Risk-sharing and Islamic preferred shares. *Journal of Business Ethics*, *124*(4), 623–632.
- Anouze, A. L., & Bou-Hamad, I. (2021). Inefficiency source tracking: Evidence from data envelopment analysis and random forests. *Annals of Operations Research*. <https://doi.org/10.1007/s10479-020-03883-3>
- Anwar, S. M., Junaidi, J., Salju, S., Wicaksono, R., & Mispiyanti, M. (2020). Islamic bank contribution to Indonesian economic growth. *International Journal of Islamic and Middle Eastern Finance and Management*, *13*(3), 519–532. <https://doi.org/10.1108/IMEFM-02-2018-0071>
- Bakin, S., Hegland, M., & Osborne, M. R. (2000). Parallel MARS algorithm based on B-splines. *Computational Statistics*, *15*, 463–484. <https://doi.org/10.1007/PL00022715>
- Belanès, A., Fiti, Z., & Regaïeg, R. (2015). What can we learn about Islamic banks efficiency under the subprime crisis? Evidence from GCC Region. *Pacific-Basin Finance Journal*, *33*, 81–92. <https://doi.org/10.1016/j.pacfin.2015.02.012>
- Bhambri, V. (2011). Application of data mining in banking sector. *International Journal of Computer Science and Technology*, *2*(2), 199–202.
- Bhasin, M. L. (2006). Data mining: A competitive tool in the banking and retail industries. *The Chartered Accountant*, *55*(4), 588–594.
- Bitar, M., Hassan, M. K., & Walker, T. (2017). Political systems and the financial soundness of Islamic banks. *Journal of Financial Stability*, *31*, 18–44.
- Bosman, N., & Frecher, F. (1992). Une étude comparative de l'efficacité technique du secteur de la santé au sein des pays de l'O.C.D.E. Working Paper, 92/08, CIRIEC, Université de Liège.
- Boukhatem, J., & Moussa, F. B. (2018). The effect of Islamic banks on GDP growth: Some evidence from selected MENA countries. *Borsa Istanbul Review*, *18*(3), 231–247.
- Bourakba, C. (2014). The Impact of corporate governance in the financial performance of Islamic banks: Evidence from the GCC region. *Journal of US-China Public Administration*, *11*(8), 633–641.

- Cai, S., & Zhang, J. (2020). Exploration of credit risk of P2P platform based on data mining technology. *Journal of Computational and Applied Mathematics*, 372, 112–118.
- Chen, Y. J., Lin, J. A., Chen, Y. M., & Wu, J. H. (2019). Financial forecasting with multivariate adaptive regression splines and queen genetic algorithm-support vector regression. *IEEE Access*, 7, 112931–112938.
- Choong, Y. V., Thim, C. K., & Kyzy, B. T. (2012). Performance of Islamic commercial banks in Malaysia: An empirical study. *Journal of Islamic Economics Banking and Finance*, 8(2), 67–79.
- Choudhury, M. A., & Alam, M. N. (2013). Corporate governance in Islamic perspective. *International Journal of Islamic and Middle Eastern Finance and Management*, 6(3), 180–199.
- Chowdhury, N. T., & Abduh, M. (2012). Does Islamic banking matter for economic growth in Bangladesh? *Journal of Islamic Economics, Banking and Finance*, 113(467), 1–10.
- Denison, D. G. T., Mallick, B. K., & Smith, A. F. M. (1998). Bayesian MARS. *Statistics and Computing*, 8(4), 337–346.
- Eber, N. (2000). Efficience du système bancaire, structure du marché de crédit et activité économique. *Revue Economique*, 51(6), 1333–1353.
- Farag, H., Mallin, C., & Ow-Yong, K. (2018). Corporate governance in Islamic banks: New insights for dual board structure and agency relationships. *Journal of International Financial Markets, Institutions and Money*, 54, 59–77.
- Farrell, M. J. (1957). The measurement of productive efficiency. *Journal of the Royal Statistical Society, Series A*, 120(3), 253–290.
- Friedman, J. H. (1991). Multivariate adaptive regression splines. *The Annals of Statistics*, 19(1), 1–67.
- Ghaffar, A. (2014). Corporate governance and profitability of Islamic banks operating in Pakistan. *Interdisciplinary Journal of Contemporary Research in Business*, 6(2), 320–336.
- Hamza, H. (2013). Sharia governance in Islamic banks: Effectiveness and supervision model. *International Journal of Islamic and Middle Eastern Finance and Management*, 6(3), 226–237.
- Hassan Al-Tamimi, H. A. (2010). Factors influencing performance of UAE Islamic and conventional banks. *Global Journal of Business Research*, 4(2), 1–9.
- Hassan, V., Bala, S., & Vignesén, P. (2005). *Corporate Governance: An Islamic Paradigm*. Universiti Putra Malaysia Press.
- Hopt, K. J. (2021). Corporate governance of banks and financial institutions: Economic theory, supervisory practice, evidence and policy. *European Business Organization Law Review*, 22, 13–37. <https://doi.org/10.1007/s40804-020-00201-z>
- Huynh, T. L. D., Nasir, M. A., Nguyen, S. P., & Duong, D. (2020). An assessment of contagion risks in the banking system using non-parametric and copula approaches. *Economic Analysis and Policy*, 65, 105–116.
- Ihsan, I., & Kabir, H. M. (2002). Technical, scale and allocative efficiencies of Turkish banking industry. *Journal of Banking and Finance*, 26(4), 719–766.
- Iqbal, M., & Molyneux, P. (2005). *Thirty years of Islamic banking: History, performance and prospects*. London, UK: Palgrave Macmillan.
- Jekabsons, G. (2011). ARESLab: Adaptive regression splines toolbox for matlab/Octave. <http://www.cs.rtu.lv/jekabsons/>
- Kalaycı, B., Özmen, A., & Weber, G.-W. (2020). Mutual relevance of investor sentiment and finance by modeling coupled stochastic systems with MARS. *Annals of Operations Research*, 295, 183–206. <https://doi.org/10.1007/s10479-020-03757-8>
- Kao, L. J., Chiu, C. C., Lu, C. J., & Chang, C. H. (2013). A hybrid approach by integrating wavelet-based feature extraction with MARS and SVR for stock index forecasting. *Decision Support Systems*, 54(3), 1228–1244.
- Kassim, S. (2016). Islamic finance and economic growth: The Malaysian experience. *Global Finance Journal*, 30, 66–76.
- Kusuma, H., & Ayumardani, A. (2016). The corporate governance efficiency and Islamic bank performance: An Indonesian evidence. *Polish Journal of Management Studies*, 13(1), 111–120.
- Liébana-Cabanillas, F., Noguera, R., Herrera, L. J., & Guillén, A. (2013). Analysing user trust in electronic banking using data mining methods. *Expert Systems with Applications*, 40(14), 5439–5447.
- Manickavasagam, J., Visalakshmi, S., & Apergis, N. (2020). A novel hybrid approach to forecast crude oil futures using intraday data. *Technological Forecasting and Social Change*, 158, 120–126.
- Mensi, W., Hammoudeh, S., Al-Jarrah, I. M. W., Al-Yahyaee, K. H., & Kang, S. H. (2019). Risk spillovers and hedging effectiveness between major commodities, and Islamic and conventional GCC banks. *Journal of International Financial Markets, Institutions and Money*, 60, 68–88.
- Milborrow, S. (2019). Notes on the earth package. <http://www.milbo.org/doc/earth-notes.pdf>
- Mirakhor, A. (2008). Lesson of the recent crisis for Islamic finance. *IJUM Journal of Economics and Management*, 16(2), 132–138.

- Miyan, M. (2017). Applications of data mining in banking sector. *International Journal of Advanced Research in Computer Science*, 8(1), 108–114.
- Mollah, S., & Zaman, M. (2015). Shari'ah supervision, corporate governance and performance: Conventional vs. Islamic banks. *Journal of Banking and Finance*, 58, 418–435.
- Naushad, M., & Malik, S. A. (2015). Corporate governance and bank performance: A study of selected banks in GCC region. *Asian Social Science*, 11(9), 226–234.
- Nawaz, T. (2019). Exploring the nexus between human capital, corporate governance and performance: Evidence from Islamic Banks. *Journal of Business Ethics*, 157(2), 567–587.
- Ngo, T. T., Le, M. Q., & Ngo, T. P. (2019). Incorporating risk into technical efficiency for Vietnam's and ASEAN banks. *Journal of Asian Business and Economic Studies*, 26(1), 2–16. <https://doi.org/10.1108/JABES-10-2018-0083>
- Nkuutu, G., Ntayi, J. M., Nkote, I. N., Munene, J., & Kaberuka, W. (2020). Board governance quality and risk disclosure compliance among financial institutions in Uganda. *Journal of Asian Business and Economic Studies*, 28(1), 64–81. <https://doi.org/10.1108/JABES-04-2020-0036>
- Olson, D., & Zoubi, T. (2017). Convergence in bank performance for commercial and Islamic banks during and after the Global Financial Crisis. *The Quarterly Review of Economics and Finance*, 65, 71–87.
- Ongore, V. O., & Kusa, G. B. (2013). Determinants of financial performance of commercial banks in Kenya. *International Journal of Economics and Financial Issues*, 3(1), 237–252.
- Özmen, A. (2021). Sparse regression modeling for short- and long-term natural gas demand prediction. *Annals of Operations Research*. <https://doi.org/10.1007/s10479-021-04089-x>
- Peral, J., Maté, A., & Marco, M. (2017). Application of data mining techniques to identify relevant key performance indicators. *Computer Standards and Interfaces*, 50, 55–64.
- Platonova, E., Asutay, M., Dixon, R., & Mohammad, S. (2018). The impact of corporate social responsibility disclosure on financial performance: evidence from the GCC Islamic banking sector. *Journal of Business Ethics*, 151, 451–471.
- Quttainah, M. A., Song, L., & Wu, Q. (2013). Do Islamic banks employ less earnings management? *Journal of International Financial Management and Accounting*, 24(3), 203–233.
- Rabbouch, H., Saâdaoui, F., & Mraïhi, R. (2018). A vision-based statistical methodology for automatically modeling continuous urban traffic flows. *Advanced Engineering Informatics*, 38, 392–403.
- Riaz, S., & Mehar, A. (2013). The impact of bank specific and macroeconomic indicators on the profitability of commercial banks. *Romanian Economic Journal*, 16(47), 91–110.
- Richardson, S., Wang, S., & Jennings, L. S. (2008). A multivariate adaptive regression B-spline algorithm (BMARS) for solving a class of nonlinear optimal feedback control problems. *Automatica*, 44(4), 1149–1155. <https://doi.org/10.1016/j.automatica.2007.09.001>
- Roghianian, P., Rasli, A., & Gheysar, H. (2012). Productivity through effectiveness and efficiency in the banking industry. *Procedia—Social and Behavioral Sciences*, 40, 550–556.
- Rosman, R., Wahab, N. A., & Zainol, Z. (2014). Efficiency of Islamic banks during the financial crisis: An analysis of Middle Eastern and Asian countries. *Pacific-Basin Finance Journal*, 28, 76–90.
- Saâdaoui, F. (2012). A probabilistic clustering method for US interest rate analysis. *Quantitative Finance*, 12(1), 135–148. <https://doi.org/10.1080/14697681003591712>
- Saâdaoui, F. (2018). Testing for multifractality of Islamic stock Markets. *Physica a: Statistical Mechanics and Its Applications*, 496, 263–273.
- Saâdaoui, F., & Ben Messaoud, O. (2020). Multiscaled neural autoregressive distributed lag: A new empirical mode decomposition model for nonlinear time series forecasting. *International Journal of Neural Systems*, 30(8), 2050039. <https://doi.org/10.1142/S0129065720500392>
- Saâdaoui, F., Bertrand, P. R., Boudet, G., Rouffiac, K., Dutheil, F., & Chamoux, A. (2015). A dimensionally reduced clustering methodology for heterogeneous occupational medicine data mining. *IEEE Transactions on NanoBioscience*, 14(7), 707–715. <https://doi.org/10.1109/TNB.2015.2477407>
- Saâdaoui, F., Naïfar, N., & Aldohaiman, M. S. (2017). Predictability and co-movement relationships between conventional and Islamic stock market indexes: A multiscale exploration using wavelets. *Physica a: Statistical Mechanics and Its Applications*, 482, 552–568.
- Safiullah, M., & Shamsuddin, A. (2019). Risk-adjusted efficiency and corporate governance: Evidence from Islamic and conventional banks. *Journal of Corporate Finance*, 55, 105–140.
- Samad, A. (1999). Comparative efficiency of the Islamic bank vis-à-vis conventional banks in Malaysia. *IJUM Journal of Economics and Management*, 7(1), 1–27.
- Shahid, M. N., Abbas, A., Latif, K., Attique, A., & Khalid, S. (2020). The mediating role of board size, philanthropy and working capital management between basic corporate governance factors and firm's performance. *Journal of Asian Business and Economic Studies*, 27(2), 135–151. <https://doi.org/10.1108/JABES-07-2018-0050>

- Shibani, O., & De Fuentes, C. (2016). The differences and the similarities between corporate. *Economics*, 34(8), 506–524.
- Soumya, S. B., & Deepika, N. (2016). Data mining with predictive analytics for financial applications. *International Journal of Scientific Engineering and Applied Science*, 2(1), 310–317.
- Taffé, P. (1998). *Frontière d'efficacité et évaluation de la performance énergétique des bâtiments*. Doctoral Thesis in Economics, University of Geneva.
- Tsumoto, S., & Hirano, S. (2016). Multidimensional temporal mining in hospital information system. *International Journal of Computational Intelligence Studies*, 5(3/4), 317–337.
- Ur Rehman, R., & Mangla, I. U. (2010). Corporate governance and performance of financial institutions in Pakistan: A comparison between conventional and Islamic banks in Pakistan. *The Pakistan Development Review*, 49(4), 461–475.
- Yucel, M., Aslan, Z., and Burunkaya, M., (2020). Classification of the temperature-dependent gain of an erbium-doped fiber amplifier by using data mining methods, *Optik*, vol. 208, Article Number: 164515.
- Zeitun, R. (2012). Determinants of Islamic and conventional banks performance in GCC countries using panel data analysis. *Global Economy and Finance Journal*, 5(1), 53–72.
- Zhu, Y., Zhou, L., Xie, C., Wang, G. J., & Nguyen, T. V. (2019). Forecasting SMEs' credit risk in supply chain finance with an enhanced hybrid ensemble machine learning approach. *International Journal of Production Economics*, 211, 22–33.

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