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Developing a hybrid analytics approach to measure the efficiency of deposit banks

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ABSTRACT

This study aims at analyzing the efficiency of deposit banks using contemporary analytics-based decision-making techniques within a fuzzy environment. Specifically, a hybrid analytic model drawing on a fuzzy analytical network process and data envelopment analysis was developed and applied to the assessment of Turkish deposit banks quoted on Borsa Istanbul. The findings revealed that; (i) the efficiency results for banking activity vary for competitiveness and for the adoption of new technologies before and after the financial recession; (ii) the majority of deposit banks operating primarily with non-interest based factors found to be less-efficient; (iii) the ownership and capital structure of banks do not significantly contribute to their banking performance, as they were technically inefficient during the same period; and (iv) the inputs of the banking activities could be reduced while a constant level of output is maintained by adopting and properly using the most efficient technology to boost the technical efficiency.

1. Introduction

The latest ramifications of the global recession on economic activity in emerging markets have increased tensions on corporate performance as well as on the investment environment. Besides the financial stress in the banking sectors in the advanced economies following the recession significantly contributed to a sharp decline in banking performance worldwide, and this was reflected in security markets globally as well. The channels of the financial distress in the global financial system dramatically affected the operations of the banking sectors in advanced/developed and emerging economies, almost simultaneously (Eaton, Kaiser, & Smoke, 2011; Hackbarth, Haselmann, & Schoenherr, 2015; Nijskens & Wagner, 2011; Paulson, 2010). Consequently, less than optimal banking performance in advanced economies led to significant fluctuations in the markets. Because of the doubts about the financial stability in the capital markets, investors preferred assets at the lowest risk level, mainly for security and liquidity purposes.

The banking sector is a vital part of the globalized financial system, as banks play an intermediary role in international trade and investment. Furthermore, the global risks and ambiguities of multinational enterprises shifted from advanced economies to emerging markets through this intermediation function of the banking system. During the recession, with its impact on banking activities and the intermediation function, some measures and regulatory reforms have been implemented for the restoration of the financial system. Nonetheless, sovereign vulnerabilities, the lack of effective policies on the deleveraging process, low asset quality, an inefficient securitization process, liquidity mismatching, and increasing third-party risks were some of the critical sources of financial stress which could pose threats to the normalization of the global financial system (Cardarelli, Elekdag, & Lall, 2011; Danninger, Tytell, Balakrishnan, & Elekdag, 2009; Hakkio & Keeton, 2009; Illing & Liu, 2006). Following the turmoil in the advanced economies, questions about banking performance and concerns with efficiency were linked to worries about the financial stability and smooth normalization, while banks were still the significant intermediaries facilitating international fund transfers and transactions in the financial system. The systemic risk over the last decade has become the major challenge for banking stability and sectoral growth. Some functions of banks, including their function of providing cost advantages, transforming risks, and channeling funds for financial actors,

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are the fundamental activities within this intermediation process which might be exposed to systemic risk and might be attached to some critical financial stress indices (Bremus & Buch, 2015; Carretta, Farina, Fiordelisi, Schwizer, & Lopes, 2015; Engle, Jondeau, & Rockinger, 2015; Giglio, Kelly, & Pruitt, 2015; Louati, 2015). The risk to global financial stability and poor banking performance dramatically decreased asset quality, as it revealed the fact that the capital structure in the banking sector was expected to adapt to changes as part of the regulatory reforms.

The regulatory reforms in the banking sectors require some financial policy implementations for the increase of capital, the accommodation of high-quality liquid assets, and preventive actions for toxic assets which have resulted in poor banking performance outcomes (Ononaiwu, 2015; Qureshi, Diaz-Sanchez, & Varoudakis, 2015). Moreover, these regulatory reforms in banking, risk management practices, and capital management decisions created a perplexing situation concerning banking stability and profitability. Notwithstanding this, the expectations of more excellent stability in the banking sectors in the advanced and emerging economies required some successful shifts from high growth prospects to the successful implementation of regulatory reforms. Despite brighter growth prospects and profitability, the deleveraging process in the banking industry led to poor banking performance and a decline in the scale efficiencies (DeAngelo & Stulz, 2015; Frey & Kerl, 2015). In this context, doubts about the efficiency levels of the banking sectors based on the technology, scale, cost, and profit patterns in emerging economies became challenging concerns faced by the top decision makers. Despite this, the decision makers are expected to solve efficiency-based performance problems during volatile market conditions. Briefly, the factors involved in changing the banking environment and the regulatory reforms are challenging issues for bank efficiency levels, as interest and non-interest income-based banking activities are attached to performance inputs and outputs, such as capital ratio, liability quality, asset quality, income structure, expenditure structure, return on equity, and return on assets (Daly & Frikha, 2015; Ghosh, 2015).

The global economic outlook during the recession and its manifestation of the instability in the global financial system, which was mostly based on structural problems and riskiness, led to some compelling challenges for managers, prompting them to develop cost and profit efficiency-based strategies. As a reflection of the increasing financial distress in the capital markets through economic channels, some significant concerns regarding poor banking performance became challenging issues within the investment environment. In this context, the selection of practical decision-making tools for banking activities and portfolio investment strategies played a critical role. As a reaction to this, top class managers have been seeking new ways to adopt novel techniques, decision making models, strategies to boost corporate performance, and efficiency, even though they have either a technical base or profit base (Allen & Gale, 2004; Andrieş, Cocriş, & Ursu, 2012; Apergis, 2015; Bikker & Spierdijk, 2008; Cetorelli & Gambera, 2001; Daly & Frikha, 2015; Irisappane & Sundar, 2015; Jana & Thakur, 2015).

This study primarily seeks answers to the following research questions: (1) What kind of methods and decision-making tools should be adopted to prevent any clash between high efficiency-based performance policies and stable banking operations in light of the latest regulatory reforms? (2) Are there any effective ways to boost banking performance towards a high level of efficiency and profitability with a secured level of assets and capital? (3) Is the use of new hybrid techniques capable of preventing future shocks for the banking industry? (4) How can the efficiency of the Turkish banking sector be improved in the financial crisis period?

In this study, the aim is to analyze the efficiency level of deposit banks using modern analytics-based techniques (i.e., multi-criteria decision-making methods) within a fuzzy environment in order to provide a strong, evidence-based basis for accurate and timely decision making. Accordingly, a hybrid analytic model was designed and developed, and then applied to rank/compare the efficiency trends of the Turkish deposit banks, which were quoted on the Borsa Istanbul (BIST). A fuzzy analytical network process (FANP) and a data envelopment analysis (DEA) were developed and used to measure the efficiency of the decision-making units (DMUs) and to assess the efficiency trends. Following the determination of the proposed inputs and outputs of banking efficiency based on a review of the relevant literature along with the inputs/opinions elicited from the domain experts, the proposed model designs and executed the FANP methodology to calculate the weights of the input and output factors of the banking activities. Then, the weighted data set is used to assess the efficiency scores. Accordingly, in the following sections, the paper provides the background and motivation for the topic, followed by the details about the proposed hybrid methodology, the application of the methodology to BIST, presentation of the impressive results obtained from the study, and finally concluding the paper with related remarks/discussions and implications.

2. Background and literature review

The extant literature on measuring the efficiency and performance of banks in advanced and emerging economies has expanded significantly over the last couple of decades, especially following the recent turmoil in the global financial system.

The previous research was driven mainly by the constant challenges in the banking sector. The studies on banking performance linked the efficiency of banks to several traditional concerns regarding banking activities, cost-based efficiency, technology-based efficiency, ownership, capital structure, and market-based determinants, such as risk, liquidity, and integration. Even though there is a large body of literature on banking efficiency, there is still a paucity of research on the bank efficiency trends that rely on novel analytic models and decision-making tools. Table 1 provides a summary of the selected studies regarding the effects of the global financial crisis on banking activities and their efficiencies.

The recent studies demonstrate a secure link between stable banking performance, cost efficiency, profitability, and competitiveness. Nguyen (2018) highlighted that income diversification, and asset diversification would negatively impact the cost efficiency of ASEAN commercial banks and funding diversification would make foreign banks less profit efficient. Tan (2016) dealt with the measurement of bank efficiency and the competition of Chinese commercial banks. He noted that the competitive environment was highly related to the efficiency of the banking industry. Based on a sample of banks from the Philippines, Manlagnit (2015) applied a stochastic cost frontier analysis to determine the effects of regulatory changes and applications on banking efficiency, using the theoretical model to estimate the cost efficiency. The numerical efficiency values and particular rankings were obtained by measuring the relative performance of the banks, and it was found that a higher capital requirement tended to improve the cost efficiency, but that more powerful supervisors could adversely affect the efficiency of the banks. Based on the empirical study by Aiello and Bonanno (2016), bank efficiency has been analyzed using a stochastic frontier analysis for costs and profits. The authors evaluated the impact of local market conditions on the efficiency of small mutual-cooperative banks. Concerning the theme of the empirical analysis of cost and profit efficiency in the Italian banking sector, the distinguishing finding refers to the performance of mutual-cooperative banks, which increases with the market concentration and demand density and decreases as bank branches increase in local markets. Based on application, the significant findings demonstrate that the cost efficiency of banks negatively decreases based on local development, while banks generate more profit when the systemic credit risk increases (Aiello & Bonanno, 2016).

Within the context of the MCDM framework, Quaranta, Raffoni, and Visani (2018) developed a multidimensional approach to analyzing branch efficiency of Italian banks and confirmed the potential

Table 1
Selected studies on banking efficiency.

Author	Subject	Specific variables	Analysis & method	Findings
Konara et al. (2019)	Foreign direct investment; efficiency;	Capital; risk; bank size; GDP; financial crisis; trade openness	Panel data	The findings show that foreign banks have the advantages of technical and scale efficiencies except the pure technical, cost, and revenue efficiency.
Doan et al. (2018)	Bank efficiency; income diversification	The value of income diversification; the share of non-interest income; ownership types	stochastic frontier approach	They figured out that increasing diversification could improve the efficiency and this situation could cause to the volatile effects on non-interest activities.
Nguyen (2018)	Bank efficiency; Cost efficiency and Income diversification	Asset; Funding; Income	stochastic frontier approach	More income-diversified banks have lower cost efficiency while more asset-diversified banks have only lower persistent cost efficiency.
Quaranta et al. (2018)	Banking performance and efficiency	19 financial ratios for 23 bank branches	collinearity analysis and clustering	a multidimensional approach to analyzing the branch efficiency is confirmed for the Italian banks.
Haque and Brown (2017)	Banking ownership; concentration	Income; size; deposit; interest; GDP	Regression model	The concentration has an impact on the ownership affects the banking performance positively.
Othman et al. (2017)	Banking efficiency; partnership	Operating expense; earning assets; equity	Panel data	Large partnership financing are more efficient than other banks except during the period of financial crisis.
Du and Sim (2016)	Merger and acquisitions; efficiency	Fixed assets; non-interest operating expenses; interest expenses; net interest income; other operating income	Data envelopment analysis	The results demonstrate that the banks after the merger and acquisitions tend to be more efficient.
Tan (2016)	Bank efficiency and competition	Banking Competition Ratios	stochastic frontier approach; distribution-free approach	The competition of Chinese commercial banks is highly related to the efficiency of the banking industry.
Wanke et al. (2016)	Banking efficiency and competition	Total assets; equity; net income; customers'deposits; provisions; personal expenses; banking product; number of employees	Multicriteria decision making model	The results show that the banking industry would benefit from the competition more comprehensively by considering the cost structure and country origin of the bank.
Aiello and Bonanno (2016)	Bank efficiency and market condition; Cost efficiency; Profit efficiency	Bank Specific Variables: Loans/Deposits; Equity/Total Assets; Capital structure. Market specific variables: Market concentration; Demand density; GDP per capita; Branches density	Stochastic cost frontier analysis	Cost efficiency of banks are negatively decreasing based on local development while banks generate more profit when systemic credit risk increases.
Stewart et al. (2016)	Banking efficiency	Bank specific variables: Number of employees; Funds; Deposits; Loans and securities	Data envelopment analysis	Large banks are more efficient than small and medium sized banks. However, banks with large branch networks are less efficient banks.
Manlagnit (2015)	Bank efficiency; Cost efficiency	*Bank Based Variables*: Loans to deposits; Deposit-to-liability ratio. *Regulation Variables*: Capital requirement; Supervisory; Private monitoring. *Risk and Asset Quality Variables*: LLP/Total Loans; Equity/Total Asset	Stochastic cost frontier analysis	Higher capital requirement tends to improve the cost efficiency but more powerful supervisors can adversely affect the efficiency of the banks.
Tsionas et al. (2015)	Technical and allocative efficiency; Banking system efficiency	Bank specific variables: Total assets; liquidity ratio; interbank ratio; capital ratio.	Bayesian dynamic frontier model	During crisis banks with more stable financial position in terms of their liquidity and capital are more resistant to the shock.
Řepková (2015)	Banking efficiency	ROA; Interest rate; GDP per capita; Liquidity risk; Riskiness of portfolio; level of capitalization	Data envelopment analysis; Panel data analysis	The level of capitalization, liquidity risk and riskiness of portfolio had a positive impact on banking efficiency.
Stoica et al. (2015)	Banking performance and efficiency; Financial innovation	Financial input variables: Deposits; Total deposits and remittances. Internet banking inputs. Banking strategies: Cost oriented and innovation oriented strategies	Data envelopment analysis; Principle Component Analysis	Efficiently adopted Financial Innovation strategies have some positive effects on banking efficiency.
Luo (2015)	Banking performance and efficiency; Corporate performance	Ownership structure; Executive compensation; ROE; CEO power	Cross sectional OLS and FE panel analysis	Relationship between management compensation, CEO power and firm performance is in line with shareholders' interest.
Sokic (2015)	Banking efficiency; Cost efficiency	Bank specific variables: Equity to assets, Loans loss provisions to loans; Cash to assets; Cost to assets; Loans to assets; Bank size; Ownership; Country specific variables	Stochastic frontier analysis	Higher capitalized banks and banks with lower non-performing loans operated at higher cost efficiency.
Ulas and Keskin (2015); Zimková (2014)	Banking efficiency; Technical efficiency; Allocative efficiency; Super efficiency	Bank specific variables: Bank structure; Employees; Total assets; Total deposits; Net profit; Net interest income	Data envelopment analysis; Bayesian dynamics frontier model	Pure technical efficiency contributes more as compared with technical efficiency.
Jayaraman and Srinivasan (2014)	Banking efficiency; Profit efficiency	Banking structure; Banking size; Bank specific determinants: operational costs; non-performing assets; non-interest income.	Nerlovian profit indicator approach.	Branch operational costs, nonperforming assets, and non-interest income affect profit efficiency while the impact of technical inefficiency on profit inefficiency is minimal in comparison to allocative inefficiency which indicates better managerial performance of banks.

effectiveness of the 3-step approach. Wanke, Azad, Barros, and Hassan (2016) investigated the efficiency of the Islamic banking industry with TOPSIS and neural networks. The results show that the banking industry would benefit from the competition more comprehensively by considering the cost structure and country origin of the bank. Řepková (2015) applied the DEA and panel data analysis to determine the bank efficiency determinants in the Czech banking sector and illustrated the positive effects of the level of capitalization, liquidity risk, and the riskiness of the portfolio on banking efficiency (Řepková, 2015). Stoica, Mehdian, and Sargu (2015) evaluated the role of Internet-based innovation strategies using DEA. Based on the cost-oriented and Internet-based innovation strategies of banks, they showed that financial innovation strategies that effectively adopted have some positive effects on banking efficiency (Stoica et al., 2015).

Concerning the theme of the factors that determine bank efficiency, it is worth noting that there are some studies on the effects of executive compensation strategies, ownership structure, and CEO power on banking performance. For instance, Stewart, Matousek, and Nguyen (2016) analyzed bank efficiency in Vietnam based on the banking structure and ownership and briefly explored the determinants of bank efficiency. They argued that banks with large branch networks are less efficient. Their study demonstrated that non-state-owned banks are more efficient than other banks. Luo (2015) adopted a cross-sectional ordinary least squares (OLS) and fixed effects (FE) panel analysis to determine bank efficiency and assessed the relationship between management compensation, CEO power, and firm performance. More recently, Doan, Lin, and Doong (2018) evaluated the ownership structure of banks and the role of diversification on cost efficiency. They figured out that increasing diversification could improve efficiency, and this situation could lead to the subtle effects on non-interest activities. Haque and Brown (2017) considered the effects of the ownership, regulation, and supervision on the efficiency in the MENA banking sector. Accordingly, they found that the concentration on ownership affects banking performance positively.

Cost efficiency-based studies in the literature have mostly been attached to bank-specific and country-specific variables. Ownership structure, monetary practices in the market, and operating expenses are some determinants of the level of cost efficiency. Othman, Abdul-Majid, and Abdul-Rahman (2017) examined the effect of partnership financing on bank efficiency and offered that substantial partnership financing is more efficient than other banks except during the period of the financial crisis. Sokic's (2015) studied on the cost efficiency of the banking industry, and unilateral *euroization* showed that more highly capitalized banks and banks with lower non-performing loans operated at higher cost efficiency. Jayaraman and Srinivasan (2014) provided a holistic approach to measure the profit efficiency of banks using the *Nerlovian Profit Indicator* approach. In their study, the profit inefficiency of banks was decomposed into technical and allocation inefficiency using the directional distance function. One of their significant findings was that, compared to small and medium-sized banks, profit inefficiency is higher for large-sized banks. Their results suggested that banks need to focus on branch operational costs, nonperforming assets, and non-interest income to enhance profit efficiency, while the impact of technical inefficiency on profit inefficiency is minimal in comparison to allocative inefficiency, which indicates a better managerial performance of banks.

Another aspect of the banking efficiency studies in the literature is related to the technical and scale efficiencies of banks in advanced and emerging economies. Konara, Tan, and Johnes (2019) examined the impact of foreign direct investment with the internal and external measures of efficiency in the emerging banking sector. The findings show that foreign banks have the advantages of technology and scale efficiencies except for pure technical, cost, and revenue efficiency. Du and Sim (2016) focused on the merger, acquisitions, and bank efficiency with cross-country evidence from emerging markets. The results demonstrate that the banks after the merger and acquisitions tend to be more efficient. Ulas and Keskin (2015) used a DEA for commercial banks in Turkey in order to analyze their level of technical efficiency. Individual banks were ranked based on their technical efficiency scores. The state-owned banks in their study were the most efficient banks in Turkey, and they were compared with other banks based on pure technical efficiency. Tsionas, Assaf, and Matousek (2015) analyzed the major short-run and long-run performance differences in the European banking system. They argued that efficiency dropped in most countries following the crisis; however, the long-run results suggested an improvement, both in terms of technical and allocative efficiencies in the banking system. The studies on banking efficiency and corporate performance shed some light on the relationships between performance and stock market returns. Edirisuriya, Gunasekarage, and Dempsey (2015) studied bank diversification, performance, and stock market response. Their study showed that in banks with a high level of diversification from interest-only income, it is possible to achieve higher market-to-book valuations and improved solvency. Briefly, they argued that the level of diversification and banking performance affect the stock market response. Soumadi and Hayajneh (2015) developed an empirical study on the effects of capital structure on corporate performance in the stock market. They found that there is no difference between the financial leverage of high growth firms and low growth firms on such performance.

Most of the efficiency-based studies on banking performance, as evident from the cited literature above, have been devoted primarily to cost-based, profit-based, and technology-based efficiencies measures. Some of these empirical studies have measured the *bank-specific determinants* for interest income and non-interest income banking activities. Building on this body of knowledge, in this study, we used such determinants as performance inputs and outputs; namely, capital ratio, liability quality, asset quality, income structure, expenditure structure, return on equity, and return on assets.

3. Methodology

3.1. Fuzzy analytic network process

The analytic network process (ANP) is a generalization of the analytic hierarchy process (AHP) first introduced by Saaty (1980). This method is mainly used in the application of multi-criteria decision making for solving economic and business problems (Gao & Hailu, 2012; Kutlu & Ekmekçioglu, 2012; Saaty, 1980; Wang & Chen, 2007; Yu, Guo, Guo, & Huang, 2011). The ANP provides a general framework to decide without any assumptions about the independence of higher-level elements from low-level elements and the independence of the elements within a level (Gencer & Gürpinar, 2007). In this way, it is possible to uncover the judgments of decision makers and to structure the weights of the criteria in non-hierarchical conditions that have dependencies among directions (Lee & Kim, 2001).

The ANP feedback approach considers the hierarchies in the different levels of network relationships. The structural differences between the AHP and ANP systems are graphically illustrated in Fig. 1 (Büyükyazıcı & Sucu, 2003; Gencer & Gürpinar, 2007; Görener, 2012; Sadeghi, Rashidzadeh, & Soukhakian, 2012).

Interdependency between two clusters, called outer dependence, is represented by a two-way arrow or by arcs that graphically represent the interdependencies among the different levels of criteria. Interdependencies are represented as a looped arc indicates the interdependencies within the same level of analysis in an ANP approach (Chung, Lee, & Pearn, 2005; Jharkharia & Shankar, 2007).

Most of the real-world multi-criteria decision-making problems are not suitable for the hierarchical structure unless the criteria interactions are omitted. Incidentally, Saaty (1996) proposed using the ANP in the case of problems that have dependence among the criteria or alternatives. However, studies conducted over the last decade show that the fuzzy-based models have been widely used in the ANP to obtain priorities where there is uncertainty, with inter-dependency among the

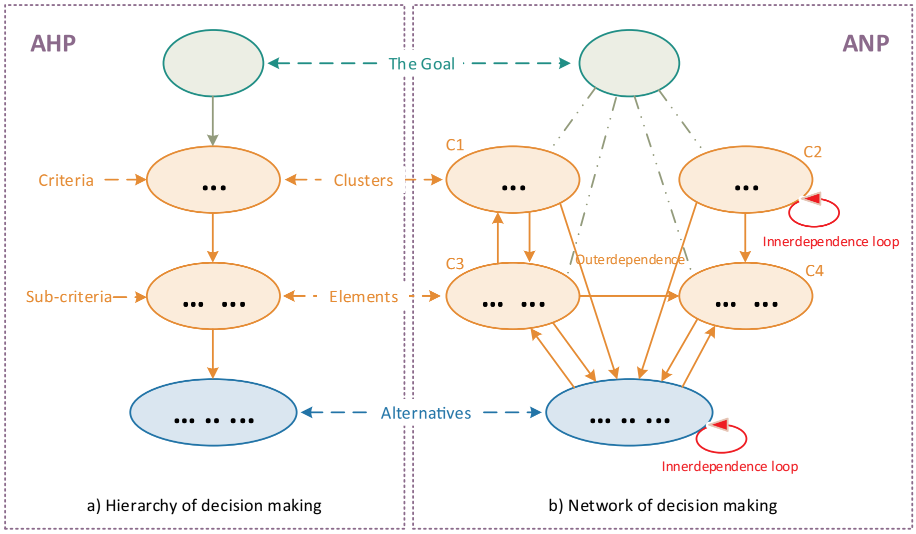

Fig. 1. A comparative structure of AHP and ANP models.

criteria or alternatives (Ayağ & Özdemir, 2007; Büyüközkan & Çifçi, 2012; Chang, Kuo, Wu, & Tzeng, 2015; Chen & Chen, 2010; Dağdeviren, Yüksel, & Kurt, 2008; Lee, 2013; Lee, 2015; Mohanty, Agarwal, Choudhury, & Tiwari, 2005; Önüt, Kara, & Işik, 2009; Shafiee, 2015; Yüksel & Dağdeviren, 2010).

Judgment with fuzziness is often expressed by fuzzy sets and is performed by linguistic methods (Ma, Lu, & Zhang, 2010). The ANP-based weights of the criteria under a fuzzy environment are determined in the following pair-wise comparison decision matrix.

$$\widetilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \tilde{a}_{13} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \tilde{a}_{23} & \cdots & \tilde{a}_{2n} \\ \tilde{a}_{31} & \tilde{a}_{32} & 1 & \cdots & \tilde{a}_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \tilde{a}_{n3} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} 1 & \tilde{a}_{12} & \tilde{a}_{13} & \cdots & \tilde{a}_{1n} \\ 1/\tilde{a}_{12} & 1 & \tilde{a}_{23} & \cdots & \tilde{a}_{2n} \\ 1/\tilde{a}_{13} & 1/\tilde{a}_{23} & 1 & \cdots & \tilde{a}_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{a}_{1n} & 1/\tilde{a}_{2n} & 1/\tilde{a}_{3n} & \cdots & 1 \end{bmatrix} \tag{1}$$

The FANP approach, with Chang's extent analysis method, has been considered to calculate the weights of the input and output factors of the proposed banking activities. Let$X = \{x_1, x_2, \ldots, x_n\}$ be an object set, and $U = \{u_1, u_2, \ldots, u_n\}$ be a goal set. Chang's extent analysis method provides that each object is taken and an extensive analysis for each goal is performed (Chang, 1996). So, m extent analysis values for each object can be attained with:

$$M_{gi}^1,\ M_{gi}^2,\ \ldots, M_{gi}^n, \quad i = 1,\ 2,\ \ldots n, \tag{2}$$

where all the $M_{gi}^j (j = 1, 2, \ldots n)$ are fuzzy triangular numbers. The method can be stated in the following four main steps (Chang et al., 2015; Dağdeviren et al., 2008; Lee, 2013; Shafiee, 2015; Yüksel & Dağdeviren, 2010).

Step 1: The value of fuzzy synthetic extent concerning the ith object is defined as:

$$S_j = \sum_{j=1}^{m} M_{gi}^j \otimes \left(\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right)^{-1} \tag{3}$$

To obtain $\sum_{j=1}^{m} M_{gi}^j$, perform the fuzzy addition operation of m extent analysis relative to values for a particular matrix such that:

$$\sum_{j=1}^{m} M_{gi}^j = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j \right) \tag{4}$$

Also, to obtain $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1}$, perform the fuzzy addition operation $M_{gi}^j (j = 1, 2, \ldots m)$ of values such that:

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j = \left(\sum_{j=1}^{m} l_i, \sum_{j=1}^{m} m_i, \sum_{j=1}^{m} u_i \right) \tag{5}$$

Then compute the inverse of the vector in Eq. (5) such that:

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i} \right) \tag{6}$$

Step 2: The degree of the possibility of $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$ is defined as:

$$V(M_2 \geq M_1) = \sup[\min(\mu_{M_1}(x), \mu_{M_2}(y))] \tag{7}$$

and can be equivalently expressed as follows:

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M_2}(d)$$
$$= \begin{cases} 1, & if \quad m_2 \geq m_1, \\ 0, & if \quad l_1 \geq u_2, \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & otherwise \end{cases} \tag{8}$$

where d is the ordinate of the highest intersection point D between μ_{M_1} and μ_{M_2} to compare M_1 and M_2, the values of $V(M_1 \geq M_2) V(M_2 \geq M_1)$ and are needed.

Step 3: The degree possibility for a convex fuzzy number to be higher than k convex fuzzy numbers $M_i (i = 1, 2, \ldots, k)$ can be defined by

$$V(M \geq M_1, M_2, \ldots M_k) = V[(M \geq M_1) and (M \geq M_2) and \ldots and (M \geq M_k)]$$
$$= \min V(M \geq M_i),$$
$$i = 1,\ 2, \ldots, k \tag{9}$$

Assume that

$$d'(A_i) = \min V(S_i \geq S_k) \tag{10}$$

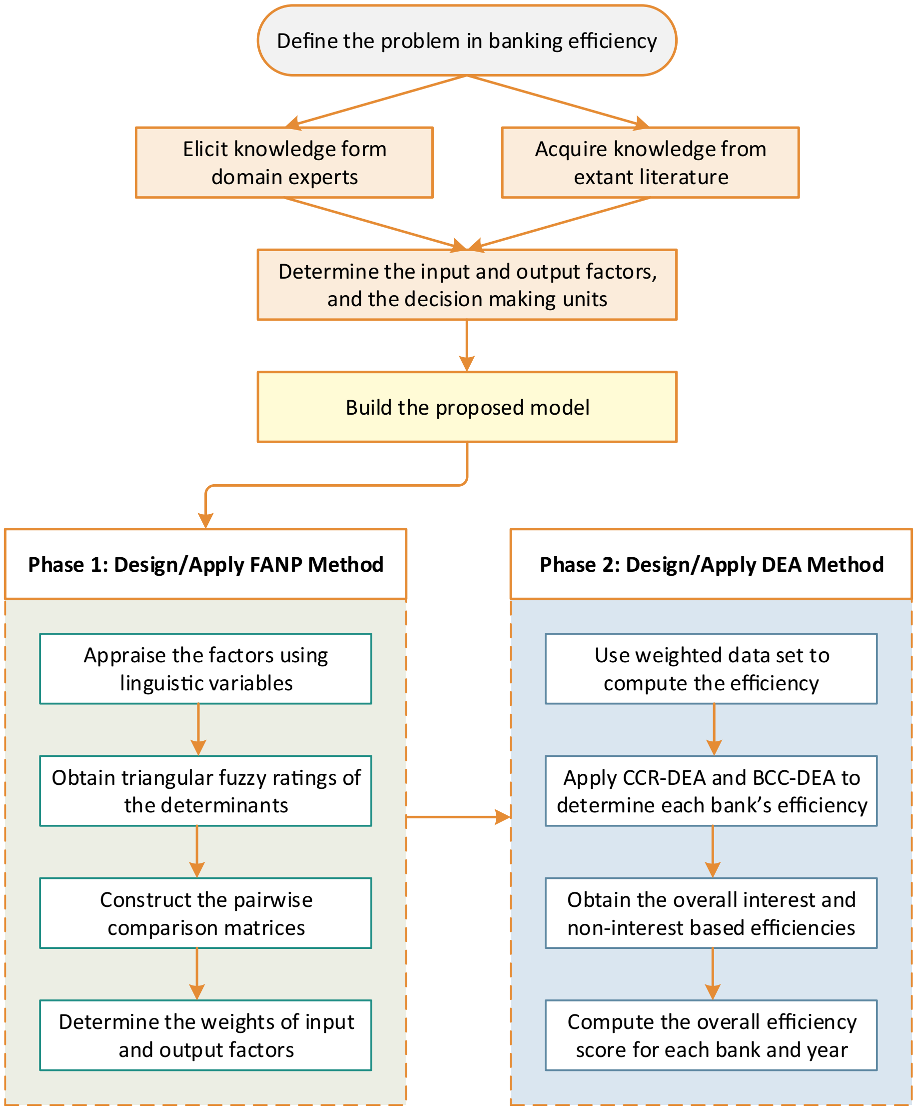

Fig. 2. Conceptual flow of the proposed hybrid model for the banking efficiency trends.

Table 2
Proposed inputs and outputs of the banking efficiency.

Description	Interest income-based	Non-interest income-based	Overall
Inputs			
Capital Ratio	Shareholders' Equity/Total Assets	Shareholders' Equity/Total Assets	Shareholders' Equity/Total Assets
Liability Quality	Total Deposits/Total Assets		Total Deposits/Total Assets
Asset Quality	Permanent Assets/Total Assets	Permanent Assets/Total Assets	Permanent Assets/Total Assets
Asset Quality	Financial Assets (Net)/Total Assets		Financial Assets (Net)/Total Assets
Expenditure Structure	Other Operating Expenses/Total Assets	Other Operating Expenses/Total Assets	Other Operating Expenses/Total Assets
Expenditure Structure	Interest Expense/Total Assets		Interest Expense/Total Assets
Outputs			
Return on Equity	Net Profit (Losses)/Total Shareholders' Equity	Net Profit (Losses)/Total Shareholders' Equity	Net Profit (Losses)/Total Shareholders' Equity
Return on Assets	Net Profit (Losses)/Total Assets	Net Profit (Losses)/Total Assets	Net Profit (Losses)/Total Assets
Asset Quality	Total Loans and Receivables/Total Assets		Total Loans and Receivables/Total Assets
Income Structure	Interest Income/Total Assets		Interest Income/Total Assets
Income Structure		Non-Interest Income (Net)/Total Assets	Non-Interest Income (Net)/Total Assets

for $k = 1, 2, \ldots, nk \neq i$; Then the weight vector is given by

$$W' = (d'(A_1), d'(A_2), \ldots, d'(A_n))^T, \quad (11)$$

where $A_i (i = 1, 2, \ldots, n)$ are n elements.

Step 4: Via normalization, the normalized weight vectors are

$$W' = (d(A_1), d(A_2), \ldots, d(A_n))^T, \quad (12)$$

where W is a nonfuzzy number.

3.2. Data envelopment analysis

The DEA was first introduced by Charnes, Cooper, Rhodes, and

 Journal of Business Research 104 (2019) 131–145

Table 3
The fuzzy scale of pair-wise comparison.

Definition	Triangular fuzzy scale		
Equally important (EI)	0,5	1	1,5
Weakly more important (WI)	1	1,5	2
Strongly more important (SI)	1,5	2	2,5
Very strongly more important (VI)	2	2,5	3
Absolutely more important (AI)	2,5	3	3,5

Source: Chang (1996); Lee (2010); Bozbura et al. (2007).

Table 4
Weights of overall inputs and outputs with Fuzzy ANP and Fuzzy AHP.

Description	FANP	FAHP
Shareholders' Equity/Total Assets (Input 1)	0.175	0.182
Total Deposits/Total Assets (Input 2)	0.236	0.202
Permanent Assets/Total Assets (Input 3)	0.116	0.125
Financial Assets (Net)/Total Assets (Input 4)	0.169	0.178
Other Operating Expenses/Total Assets (Input 5)	0.141	0.152
Interest Expense/Total Assets (Input 6)	0.163	0.161
Net Profit (Losses)/Total Shareholders' Equity (Output 1)	0.287	0.262
Net Profit (Losses)/Total Assets (Output 2)	0.205	0.183
Total Loans and Receivables/Total Assets (Output 3)	0.233	0.241
Interest Income/Total Assets (Output 4)	0.194	0.166
Non-Interest Income (Net)/Total Assets (Output 5)	0.081	0.148

Edwardo (1978), who considered the optimization of the mathematical programming to generalize Farrell's (1957) single-output/input technical-efficiency measure to multiple-output/input. Charnes et al. (1978), with their CCR model, advanced Farrell's approach, linking the estimation of technical efficiency and production frontiers.

The DEA optimizes each observation to calculate a discrete piecewise frontier situated by the set of Pareto-efficient decision-making units (DMU). The approach mainly focuses on the individual observations presented by the optimizations, instead of the averages and estimation of the parameters with single-optimization/statistical approaches. Besides, the DEA does not deal with any assumption about the imposition of a specific functional form, such as a regression equation. In this context, efficiency is constructed as a maximal performance measure for each DMU, relative to all others in the selected observation according to the constraints of the external frontier (Charnes, Cooper, Lewin, & Seiford, 1994).

In the methodology of the DEA, there are basically two main kinds of DEA models: (1) the constant returns to scale (CRS) or "CCR model", which was introduced by Charnes et al. (1978), and (2) the variable returns to scale (VRS) or "BCC model", which was adapted by Banker, Charnes, and Cooper (1984). The CCR model is a generalization of the single input and single output absolute efficiency determination of the classical approach to the multi-input and output relative efficiencies of DMUs. Thus, the multi-inputs and outputs, for efficiency, are reduced to a virtual single input and output using virtual multipliers and sums. The measure for the efficiency of the single input and the single output is the equation of output/input situated in the same units. The BCC model is one of the extensions of the CCR model, where the efficient frontiers set is determined by a convex curve passing through all efficient DMUs (Al-Faraj, Alidi, & Bu-Bshait, 1993; Ayadi, Adebayo, & Omolehinwa, 1998; Giokas, 2008; Meepadung, Tang, & Khang, 2009; Paradi, Rouatt, & Zhu, 2011; Sherman & Gold, 1985; Shyu & Chiang, 2012; Wu, Yang, & Liang, 2006a; Wu, Yang, & Liang, 2006b; Zopounidis & Doumpos, 2002).

There are two main types of DEA analyses: input-oriented and output-oriented. The input-oriented case of the DEA analysis examines the frontier by seeking the maximum possible proportional reduction in input usage while keeping output levels as constant. The output-oriented method of the DEA analysis defines the maximum proportional increase in output production, in contrast to the input levels, which are also held constant. The input and output-oriented cases of the DEA for the CCR model and BCC model can be formulated as follows (Chiou & Chen, 2006; Emrouznejad & Tavana, 2014):

The input-oriented CCR model:

$$\min z \tag{13}$$

$$s.\ t.\quad zx_{kj} \geq \sum_{l=1}^{K} \lambda_l x_{lj},\ j = 1,\ 2,\ \ldots, J \tag{14}$$

$$y_{kj} \leq \sum_{l=1}^{K} \lambda_l y_{lj},\ i = 1,\ 2,\ \ldots, I \tag{15}$$

$$\lambda_l \geq 0,\ l = 1,\ 2,\ \ldots, K \tag{16}$$

where y_{kj} denotes the ith outputs of the kth DMU. x_{kj} Represents the jth inputs of the kth DMU. λ_l It is the virtual multiplier of the lth DMU. K,I, J are the number of DMUs, inputs, and outputs, respectively. z represents the relative input efficiency of kth DMU.

The input-oriented BCC model:

$$\min z \tag{17}$$

$$s.\ t. \tag{18}$$

$$zx_{kj} \geq \sum_{l=1}^{K} \lambda_l x_{lj},\ j = 1,\ 2,\ \ldots, J \tag{19}$$

$$y_{kj} \leq \sum_{l=1}^{K} \lambda_l y_{lj},\ i = 1,\ 2,\ \ldots, I \tag{20}$$

$$\lambda_l \geq 0 l = 1,\ 2,\ \ldots, K \tag{21}$$

Table 5
Weighted data of the overall banking activities in 2013 with FANP.

DMUs	Inputs						Outputs				
	I1	I2	I3	I4	I5	I6	O1	O2	O3	O4	O5
Bank1	1.766	16.989	0.330	3.439	0.268	0.510	5.573	0.405	14.100	1.276	0.118
Bank2	1.626	14.199	0.274	2.752	0.275	0.534	3.601	0.241	14.890	1.320	0.100
Bank3	2.029	13.520	0.126	4.311	0.266	0.466	3.951	0.330	14.008	1.206	0.133
Bank4	1.001	11.360	0.302	3.269	0.334	0.592	3.675	0.151	14.374	1.471	0.076
Bank5	1.917	15.927	0.646	1.654	0.545	0.661	2.931	0.231	16.769	1.632	0.170
Bank6	2.725	15.482	0.242	1.764	0.411	0.644	2.091	0.235	17.035	1.474	0.159
Bank7	1.729	15.149	0.302	1.898	0.451	0.625	2.900	0.206	16.605	1.459	0.125
Bank8	2.004	12.760	0.310	3.213	0.302	0.529	3.814	0.315	14.017	1.255	0.141
Bank9	1.957	13.561	0.568	3.057	0.334	0.528	3.845	0.310	14.946	1.241	0.139
Bank10	2.031	13.679	0.471	2.456	0.317	0.501	5.303	0.443	15.002	1.203	0.147
Bank11	1.445	14.148	0.490	2.054	0.434	0.551	2.648	0.158	15.120	1.474	0.122
Bank12	2.024	13.699	0.326	3.096	0.492	0.620	2.751	0.229	15.052	1.666	0.141

Table 6
FANP weighted efficiency trends of the deposit banks with the overall factors.

Years		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
DMUs													
Bank1	CCR	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	BCC	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	SE	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Bank2	CCR	1.000	1.000	1.000	1.000	1.000	1.000	1.000	**0.974**	1.000	1.000	1.000	1.000
	BCC	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	SE	1.000	1.000	1.000	1.000	1.000	1.000	1.000	**0.974**	1.000	1.000	1.000	1.000
Bank3	CCR	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	BCC	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	SE	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Bank4	CCR	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	BCC	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	SE	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Bank5	CCR	1.000	1.000	1.000	1.000	1.000	1.000	1.000	**0.969**	1.000	1.000	1.000	1.000
	BCC	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	SE	1.000	1.000	1.000	1.000	1.000	1.000	1.000	**0.969**	1.000	1.000	1.000	1.000
Bank6	CCR	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	BCC	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	SE	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Bank7	CCR	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	BCC	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	SE	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Bank8	CCR	1.000	1.000	**0.993**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	BCC	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	SE	1.000	1.000	**0.993**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Bank9	CCR	**0.899**	**0.880**	1.000	1.000	**0.970**	1.000	1.000	1.000	**0.993**	1.000	1.000	**0.990**
	BCC	**0.977**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	**0.991**
	SE	**0.920**	**0.880**	1.000	1.000	**0.970**	1.000	1.000	1.000	**0.993**	1.000	1.000	**0.999**
Bank10	CCR	1.000	1.000	**0.831**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	BCC	1.000	1.000	**0.962**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	SE	1.000	1.000	**0.864**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Bank11	CCR	**0.850**	1.000	**0.894**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	BCC	**0.953**	1.000	**0.999**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	SE	**0.892**	1.000	**0.895**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Bank12	CCR	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	BCC	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	SE	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Bold values define the inefficient results of banks by years.

The output oriented CCR model:

$$\max h \quad (22)$$

$$\text{s. t. } x_{kj} \geq \sum_{l=1}^{K} \lambda_l x_{lj},\ j = 1, 2, \ldots, J \quad (23)$$

$$hy_{kj} \leq \sum_{l=1}^{K} \lambda_l y_{lj},\ i = 1, 2, \ldots, I \quad (24)$$

$$\lambda_l \geq 0,\ l = 1, 2, \ldots, K \quad (25)$$

where h presents the relative output efficiency of the kth DMU.

The output-oriented BCC model:

$$\max h \quad (26)$$

$$\text{s. t. } \sum_{l=1}^{K} \lambda_l = 1 \quad (27)$$

$$x_{kj} \geq \sum_{l=1}^{K} \lambda_l x_{lj},\ j = 1, 2, \ldots, J \quad (28)$$

$$hy_{kj} \leq \sum_{l=1}^{K} \lambda_l y_{lj},\ i = 1, 2, \ldots, I \quad (29)$$

$$\lambda_l \geq 0,\ l = 1, 2, \ldots, K \quad (30)$$

4. An exemplary case study for deposit banks

4.1. A proposed hybrid model for the analysis of the efficiency trends

The paper employs detailed input and output sets for a variety of banking efficiency settings and analyzes the efficiencies of banks in the form of multi-criteria decision-making problems. One of the conributions of this paper is to provide the inner dependencies of the input and output criteria for the banking efficiency and compare the analysis results under the hierarchical and non-hierarchical conditions. Interest, non-interest, and overall parameters of the banking efficiency are suggested for the theoretical implications, and managerial feedbacks are given by discussing the results of all input and output combinations. Thus, the policy recommendations could be constructed more comprehensively for the sustainable business results of banking efficiency.

In the literature, there are several studies on the integrated models combining the AHP and/or ANP with the DEA. Most of the researches on the DEA focus on the AHP instead of the ANP under the fuzzy environment. The scope of the hybrid models including different combinations of AHP and DEA techniques can be listed generally as transport (Lai, Potter, Beynon, & Beresford, 2015; Li, Liu, Wang, & Gao, 2016), energy (Han, Geng, & Liu, 2014; Lee et al., 2011; Lee, Mogi, & Hui, 2013; Lee, Mogi, Lee, Hui, & Kim, 2010), finance (Azadeh, Ghaderi, Mirjalili, & Moghaddam, 2011; Che, Wang, & Chuang, 2010), manufacturing (Chiang & Che, 2010; Hadi-Vencheh & Mohamadghasemi, 2011; Seifert & Zhu, 1998; Shang & Sueyoshi, 1995; Tseng, Chiu, & Chen, 2009; Yang & Kuo, 2003), telecommunication (Kumar, Shankar, & Debnath, 2015).

Table 7
FANP weighted efficiency trends of the deposit banks with the interest based factors.

Years		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
DMUs													
Bank 1	CCR	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	BCC	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	SE	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Bank 2	CCR	1.000	1.000	1.000	1.000	1.000	**0.983**	1.000	**0.972**	1.000	1.000	1.000	1.000
	BCC	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	SE	1.000	1.000	1.000	1.000	1.000	**0.983**	1.000	**0.972**	1.000	1.000	1.000	1.000
Bank 3	CCR	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	BCC	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	SE	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Bank 4	CCR	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	BCC	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	SE	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Bank 5	CCR	**0.960**	1.000	1.000	1.000	1.000	1.000	1.000	**0.965**	**0.966**	1.000	1.000	1.000
	BCC	**0.981**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	SE	**0.979**	1.000	1.000	1.000	1.000	1.000	1.000	**0.965**	**0.966**	1.000	1.000	1.000
Bank 6	CCR	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	BCC	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	SE	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Bank 7	CCR	1.000	1.000	1.000	1.000	1.000	1.000	1.000	**0.925**	1.000	1.000	1.000	1.000
	BCC	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	SE	1.000	1.000	1.000	1.000	1.000	1.000	1.000	**0.925**	1.000	1.000	1.000	1.000
Bank 8	CCR	**0.989**	**0.870**	**0.877**	**0.873**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	**0.992**
	BCC	1.000	1.000	**0.954**	**0.979**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	SE	**0.989**	**0.870**	**0.919**	**0.892**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	**0.992**
Bank 9	CCR	**0.885**	**0.863**	**0.866**	**0.933**	**0.918**	**0.909**	**0.929**	**0.894**	**0.888**	**0.947**	**0.991**	**0.983**
	BCC	**0.977**	1.000	**0.926**	1.000	1.000	**0.972**	1.000	1.000	**0.970**	**0.992**	**0.995**	**0.984**
	SE	**0.906**	**0.863**	**0.935**	**0.933**	**0.918**	**0.934**	**0.929**	**0.894**	**0.916**	**0.955**	**0.996**	**0.999**
Bank 10	CCR	1.000	**0.949**	**0.831**	1.000	1.000	**0.901**	**0.951**	**0.852**	1.000	1.000	1.000	1.000
	BCC	1.000	**0.998**	**0.962**	1.000	1.000	**0.928**	**0.955**	**0.934**	1.000	1.000	1.000	1.000
	SE	1.000	**0.951**	**0.864**	1.000	1.000	**0.971**	**0.996**	**0.912**	1.000	1.000	1.000	1.000
Bank 11	CCR	**0.794**	1.000	**0.894**	**0.921**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	BCC	**0.953**	1.000	**0.999**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	SE	**0.833**	1.000	**0.895**	**0.921**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Bank 12	CCR	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	BCC	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	SE	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Bold values define the inefficient results of banks by years.

However, the hybrid models combining ANP and DEA are narrow in the literature, and the main research interests are too limited by considering the manufacturing and managerial issues such as supplier (Abdollahi, Arvan, & Razmi, 2015; Kuo, Wang, & Tien, 2010), location (Khadivi & Ghomi, 2012), and personnel selection (Lin, 2010) as well as manufacturing programs and systems (Geng, Chu, Xue, & Zhang, 2010; Sarkis, 1999; Sen, Roy, & Pal, 2017). Moreover, there also are a limited number of studies on the hybrid technique of FANP and DEA. Rouyendegh and Erol (2010) apply this integrated method to solve the department selection problem for the universities. Wang, Nguyen, Duong, and Do (2018) use the technique to evaluate supply chain performance. However, our study provides additional contributions to the literature by applying this technique in the banking industry and comparing the results with FAHP for the banking efficiency problem.

As mentioned before, the study proposes a hybrid analytic model to analyze the efficiency trends of the banks traded on *BIST*. The model was developed by synergistically combining the FANP and DEA methods. Procedurally, the proposed model starts with the first phase, where the FANP approach is used to calculate the weights of the input and output factors of the banking activities. In the second phase of the proposed model, the weighted data set and DEA are used to obtain efficiency scores based on the three main banking activities. The conceptual process flow of the proposed model is exhibited in Fig. 2.

In this study, we use both theory and empirical approaches to banking efficiency. For that, we proposed a novel approach to the theory-based banking efficiency by constructing different sets of input and output parameters with the limitations of interest and non-interest as well as the overall effects. For this purpose, the theoretical background of Oral and Yolalan (1990) is partially adapted to our proposed banking efficiency sets to provide more comprehensive results than the classic theoretical models of banking efficiency such as service and profitability. Accordingly, the empirical application is illustrated by considering the Turkish banking industry. By considering the contributory frames of banking efficiency studies in the literature, a set of inputs and outputs of banking efficiency is constructed, and Table 2 illustrates the proposed inputs and outputs of banking efficiency for analyzing the hybrid analytic model.

The proposed model can briefly be summarized in the following steps:

Step 1: Define the problem of banking efficiency with the assumption of interdependency among the input and output factors of the banking activities and build a study group including academicians and experts in the field to define the efficiency problem in the banking sector.
Step 2: Determine the DMUs implied in the deposit banks, select the input and output factors for the different kinds of banking activities, and propose the model presented in three key banking activities described as overall, interest and non-interest banking operations.
Step 3: Use the linguistic scales to evaluate the input and output factors of the banking activities under the fuzzy environment and provide the triangular fuzzy evaluations of the input and output factors given by the decision makers.
Step 4: Weight the input and output factors of the banking activities using the pairwise comparison matrices of the factors using the FANP.

Table 8
FANP weighted efficiency trends of the deposit banks with the non-interest based factors.

Years		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
DMUs													
Bank1	CCR	1.000	**0.981**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	BCC	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	SE	1.000	**0.981**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Bank2	CCR	1.000	1.000	1.000	**0.877**	**0.722**	**0.816**	**0.797**	**0.701**	**0.848**	**0.884**	**0.793**	**0.883**
	BCC	1.000	1.000	1.000	1.000	**0.878**	**0.970**	**0.922**	**0.939**	**0.964**	**0.983**	**0.950**	1.000
	SE	1.000	1.000	1.000	**0.877**	**0.823**	**0.841**	**0.865**	**0.747**	**0.879**	**0.900**	**0.835**	**0.883**
Bank3	CCR	**0.798**	1.000	1.000	1.000	**0.914**	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	BCC	**0.973**	1.000	1.000	1.000	**0.932**	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	SE	**0.821**	1.000	1.000	1.000	**0.980**	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Bank4	CCR	1.000	1.000	1.000	**0.967**	**0.773**	1.000	**0.755**	**0.624**	**0.983**	**0.540**	**0.988**	1.000
	BCC	1.000	1.000	1.000	1.000	1.000	1.000	**0.916**	**0.835**	**0.989**	1.000	1.000	1.000
	SE	1.000	1.000	1.000	**0.967**	**0.773**	1.000	**0.823**	**0.747**	**0.994**	**0.540**	**0.988**	1.000
Bank5	CCR	1.000	1.000	1.000	1.000	1.000	**0.795**	**0.753**	**0.540**	**0.760**	**0.992**	1.000	1.000
	BCC	1.000	1.000	1.000	1.000	1.000	1.000	**0.771**	**0.719**	**0.823**	1.000	1.000	1.000
	SE	1.000	1.000	1.000	1.000	1.000	**0.795**	**0.977**	**0.751**	**0.923**	**0.992**	1.000	1.000
Bank6	CCR	1.000	**0.505**	**0.705**	**0.596**	**0.334**	**0.332**	**0.232**	**0.428**	**0.403**	**0.434**	**0.341**	**0.861**
	BCC	1.000	**0.866**	**0.883**	1.000	**0.825**	**0.717**	**0.580**	**0.511**	**0.562**	**0.677**	**0.696**	1.000
	SE	1.000	**0.583**	**0.797**	**0.596**	**0.405**	**0.462**	**0.400**	**0.837**	**0.717**	**0.641**	**0.490**	**0.861**
Bank7	CCR	**0.365**	**0.608**	**0.554**	**0.781**	1.000	**0.562**	**0.992**	**0.886**	1.000	**0.524**	**0.707**	**0.960**
	BCC	**0.828**	**0.870**	**0.872**	1.000	1.000	1.000	1.000	1.000	1.000	**0.876**	**0.780**	**0.983**
	SE	**0.440**	**0.699**	**0.636**	**0.781**	1.000	**0.562**	**0.992**	**0.886**	1.000	**0.598**	**0.907**	**0.977**
Bank8	CCR	**0.360**	**0.805**	**0.858**	1.000	**0.915**	1.000	1.000	1.000	1.000	1.000	**0.962**	1.000
	BCC	1.000	**0.968**	**0.865**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	**0.963**	1.000
	SE	**0.360**	**0.831**	**0.991**	1.000	**0.915**	1.000	1.000	1.000	1.000	1.000	**0.999**	1.000
Bank9	CCR	**0.409**	**0.684**	1.000	1.000	**0.770**	1.000	1.000	1.000	**0.960**	1.000	1.000	**0.961**
	BCC	**0.729**	**0.780**	1.000	1.000	**0.980**	1.000	1.000	1.000	1.000	1.000	1.000	**0.976**
	SE	**0.561**	**0.877**	1.000	1.000	**0.785**	1.000	1.000	1.000	**0.960**	1.000	1.000	**0.985**
Bank10	CCR	1.000	**0.658**	**0.605**	1.000	**0.823**	1.000	**0.966**	1.000	1.000	1.000	**0.857**	1.000
	BCC	1.000	**0.781**	**0.689**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	**0.858**	1.000
	SE	1.000	**0.842**	**0.879**	1.000	**0.823**	1.000	**0.966**	1.000	1.000	1.000	**0.999**	1.000
Bank11	CCR	**0.451**	**0.809**	**0.628**	**0.820**	**0.728**	**0.467**	**0.600**	**0.807**	**0.624**	**0.934**	**0.957**	**0.977**
	BCC	**0.865**	**0.928**	**0.804**	**0.906**	**0.906**	**0.879**	**0.808**	**0.839**	**0.871**	1.000	**0.967**	1.000
	SE	**0.522**	**0.872**	**0.781**	**0.905**	**0.803**	**0.532**	**0.742**	**0.963**	**0.716**	**0.934**	**0.989**	**0.977**
Bank12	CCR	**0.865**	**0.758**	**0.757**	**0.941**	1.000	**0.645**	**0.678**	**0.766**	**0.783**	**0.750**	**0.854**	**0.940**
	BCC	**0.924**	**0.774**	**0.786**	**0.954**	1.000	**0.759**	**0.945**	**0.954**	**0.826**	**0.816**	**0.877**	**0.945**
	SE	**0.937**	**0.979**	**0.964**	**0.987**	1.000	**0.850**	**0.718**	**0.803**	**0.948**	**0.920**	**0.974**	**0.995**

Bold values define the inefficient results of banks by years.

Table 9
Shares of returns to scale for the proposed banking efficiency factors with the input and output-oriented analysis between 2002 and 2013 (%).

Analysis	Input-Oriented									Output-Oriented								
Factors	Overall			Interest			Non-interest			Overall			Interest			Non-interest		
Returns to scale	CRS	IRS	DRS	CRS	IRS	DRS	CRS	IRS	DRS	CRS	IRS	DRS	CRS	IRS	DRS	CRS	IRS	DRS
DMUs																		
Bank 1	100	0	0	100	0	0	92	8	0	100	0	0	100	0	0	92	8	0
Bank 2	92	8	0	83	17	0	25	75	0	92	8	0	83	17	0	25	67	8
Bank 3	100	0	0	100	0	0	83	17	0	100	0	0	100	0	0	83	0	17
Bank 4	100	0	0	100	0	0	42	58	0	100	0	0	100	0	0	42	58	0
Bank 5	92	0	8	75	0	25	58	33	8	92	0	8	75	0	25	58	8	33
Bank 6	100	0	0	100	0	0	8	83	8	100	0	0	100	0	0	8	33	58
Bank 7	100	0	0	92	8	0	17	83	0	100	0	0	92	8	0	17	67	17
Bank 8	92	8	0	58	42	0	58	33	8	92	8	0	58	42	0	58	25	17
Bank 9	58	33	8	0	83	17	58	42	0	58	33	8	0	75	25	58	25	17
Bank 10	92	8	0	58	42	0	58	33	8	100	0	0	67	8	25	58	8	33
Bank 11	83	17	0	75	25	0	0	92	8	83	17	0	75	25	0	0	50	50
Bank 12	100	0	0	100	0	0	8	92	0	100	0	0	100	0	0	8	8	83

Step 5: Use the weighted data set to compute the efficiency scores and analyze the bank efficiency scores for the different types of banking operations using DEA by years.

Step 6: Compute the returns to scale and the average efficiency scores of the banks to compare the nature of the returns to scale and the technical, pure technical, and scale efficiencies of the banks during the studied period.

4.2. *Empirical findings*

This section presents the findings obtained from a sample of 12 most-influential deposit banks traded on *BIST*. The analysis of the scale efficiency was performed in two parts – technical and pure technical efficiency under the input and output-oriented approaches. The goal is to discuss the efficiency trends in different categories of banking activities and their potential effects on the banking sector. The initial data was collected from the annual reports and official websites of the 12

Table 10
Input and output-oriented average efficiency scores of deposit banks using the CCR and BCC models.

Analysis	Input-Oriented									Output-Oriented								
Factors	Overall			Interest			Non-interest			Overall			Interest			Non-interest		
Models	CCR	BCC	SE	CCR	BCC	SE	CCR	BCC	SE	CCR	BCC	SE	CCR	BCC	SE	CCR	BCC	SE
Years																		
2002	0.979	0.994	0.984	0.969	0.993	0.976	0.771	0.943	0.803	0.979	0.980	0.999	0.969	0.976	0.992	0.771	0.831	0.935
2003	0.990	**1.000**	0.990	0.973	**1.000**	0.974	0.817	0.914	0.889	0.990	**1.000**	0.990	0.973	0.997	0.976	0.817	0.843	0.969
2004	0.977	0.997	0.979	0.956	0.987	0.968	0.842	0.908	0.921	0.977	0.985	0.991	0.956	0.965	0.991	0.842	0.862	0.973
2005	**1.000**	**1.000**	**1.000**	0.977	0.998	0.979	0.915	0.988	0.926	**1.000**	**1.000**	**1.000**	0.977	0.996	0.981	0.915	0.980	0.935
2006	0.997	**1.000**	0.997	0.993	**1.000**	0.993	0.832	0.960	0.859	0.997	**1.000**	0.997	0.993	**1.000**	0.993	0.832	0.900	0.924
2007	**1.000**	**1.000**	**1.000**	0.983	0.992	0.991	0.801	0.944	0.837	**1.000**	**1.000**	**1.000**	0.983	0.987	0.995	0.801	0.886	0.899
2008	**1.000**	**1.000**	**1.000**	0.990	0.996	0.994	0.814	0.912	0.873	**1.000**	**1.000**	**1.000**	0.990	0.998	0.992	0.814	0.851	0.942
2009	0.995	**1.000**	0.995	0.967	0.994	0.972	0.813	0.900	0.894	0.995	**1.000**	0.995	0.967	0.989	0.978	0.813	0.858	0.940
2010	0.999	**1.000**	0.999	0.988	0.997	0.990	0.863	0.920	0.928	0.999	**1.000**	0.999	0.988	0.991	0.997	0.863	0.895	0.959
2011	**1.000**	**1.000**	**1.000**	0.996	0.999	0.996	0.838	0.946	0.877	**1.000**	**1.000**	**1.000**	0.996	0.996	**1.000**	0.838	0.905	0.924
2012	**1.000**	**1.000**	**1.000**	0.999	**1.000**	**1.000**	0.872	0.924	0.932	**1.000**	**1.000**	**1.000**	0.999	**1.000**	0.999	0.872	0.881	0.985
2013	0.999	0.999	**1.000**	0.998	0.999	0.999	0.965	0.992	0.973	0.999	0.999	**1.000**	0.998	0.999	0.999	0.965	0.991	0.974

Bold values define the inefficient results of banks by years.

banks. Initially, using the collected data, a group of academicians studied the efficiency problem in the banking sector and built the proposed input and output factors for three main banking activities classified as the overall, interest, and non-interest parameters. Afterward, ten experts (i.e., decision-makers – banking industry practitioners and consultants) were identified and appointed to form the committee to conduct the knowledge elicitation part of the study. With their input, researchers have defined the overall structure of the efficiency problem for the Turkish banking sector.

In the next step, using the problem definition from the previous step, the proposed model has been constructed by the researchers with the input from the decision makers for the comparative analysis trends of the interest, non-interest, and overall activities of 12 deposit banks listed on *BIST* between 2002 and 2013. In order to capture the true nature of the expert inputs, we have used linguistic variables for input and output factors, representing each of the linguistic variable with a triangular fuzzy membership function for the subsequent pair-wise comparison as shown in Table 3 (Bozbura, Beskese, & Kahraman, 2007; Chang, 1996; Lee, 2010).

Following the step of determining the fuzzy scale of the parameters identified and constructed by the researchers and the decision makers, the method of the fuzzy analytic network process has been applied to compute the weighted input and output factors including the interdependence among the factors.

The weights of the factors have been calculated using FANP with the Eqs. (3)–(12), and also the weighting results of the fuzzy analytic hierarchy process (FAHP) are computed to check for the robustness. Table 4 presents these comparative analysis results.

The weight results of the overall banking factors reveal that input 2, which was labeled as total deposits/total assets, has the most considerable importance, while input 3, which is permanent assets/total assets, has the smallest importance of all the input factors considered. Besides, net profit (losses)/total shareholders' equity was the best parameter weighted in the output factors, whereas non-interest income/total assets had the lowest weight of the outputs for the overall banking activities. However, the comparative results of FAHP and FANP demonstrated that the weights of the criteria are coherent according to the robustness check. The last step of the example is to compute the efficiency trends of the overall, interest, and non-interest-based activities from the weighted data set of the banks from 2002 to 2013, using the Eqs. (13)–(30). The technical, pure technical, and scale efficiency scores of the banks have also been computed to assess the efficiency results of the banks in the same period from a comparative perspective. The shares of the returns of scale and the average efficiency scores have been employed for the different types of banking activities using both the input and output-oriented methods of the DEA.

Table 5 shows the resulting values of the overall banking activities weighted with the FANP for the year 2013. The weighted data includes six inputs and five outputs of the overall banking parameters for the 12 DMUs. Table 5 is an example of the weighted data set used to compute the efficiency scores of the deposit banks in 2013.

In the study, an input-oriented DEA has been considered to evaluate the overall efficiency of the Turkish deposit banks traded on *BIST*, as seen in Table 6. An input-oriented analysis shows that the more efficient units will be better at minimizing the various costs incurred in generating the various revenue streams, and consequently, better at maximizing profits (Pasiouras, 2008).

Also, the full results of the analysis have been constructed to compare the various DEA models with the scale assumptions of the CCR and BCC approaches using Eqs. (13)–(30). Decomposing the CCR and BCC approaches helps to analyze the efficiency of the determined banking strategies over the short and long term.

The CCR efficiency scores represent the technical efficiency that measures the inefficiencies due to the input/output configuration and the size of the operations. The BCC efficiency scores determine pure technical efficiency, that is, a measure of efficiency without scale efficiency. Thus, it is possible to decompose technical efficiency into pure technical efficiency and scale efficiency. Scale efficiency can be calculated by dividing pure technical efficiency into technical efficiency (Avkiran, 2001). Besides, the banks attaining technical efficiency with a score of 1 are described as globally efficient, and the banks having a pure technical efficiency equal to 1 are known as locally efficient (Kumar & Gulati, 2008).

The empirical results demonstrate that the technical efficiency scores of the deposit banks for the overall factors are over 85% between the years of 2002 and 2013. All of the banks have 100% technical efficiency for the years 2005, 2007, 2008, 2011, and 2012. Banks 2, 5, 8, and 10 have only one year in which the technical efficiency was under 100%. Bank 9 has the worst performance for technical efficiency in the years under observation. Banks 1, 3, 4, 6, 7, and 12 have the best scores for technical efficiency, with 100% through all periods.

The results relating to pure technical efficiency for the overall banking factors show that the deposit banks have efficiency results that are better than their technical efficiency scores between the years of 2002 and 2013. Only Banks 9 and 11 in 2002, Banks 10 and 11 in 2003, and Bank 9 in 2013 have pure technical efficiency scores that are less than 100%.

The scale efficiency results for the banks are very close to the technical efficiency scores during the period. Thus, the overall results for the overall factors regarding banking efficiency show that the results for pure technical efficiency for the deposit banks are higher than their technical efficiency during the examined period. The high scores for pure technical efficiency point out that Turkish deposit banks perform well due to excellent managerial performance in their overall banking activities.

The efficiency scores of the banks with interest-based factors are indicated in Table 7. Banks 1, 3, 4, 6, and 12 remain efficient always with interest-based input and output factors during the study period. Other banks have inefficiency under the CCR and the BCC for at least one year. These results highlight that some banks have inefficiencies because of interest-based factors due to their input/output configuration and their size of operations, as well as managerial underperformance between 2002 and 2013.

As seen in Table 8, most of the banks operated their non-interest based factors in an inefficient manner. During the period, none of the banks simultaneously have had both types of technical efficiency that are equal to 1. However, only Bank 1 always has pure technical efficiency during the studied period. The outcomes reveal that banks operating with non-interest based factors remain inefficient, and the efficiency trends of the non-interest based activities show that most of the banks cannot increase their efficiency scores to 1 under the CCR and the BCC, except for Banks 1 and 3 in recent years. As a result, it is recommended that the inputs of the banking activities could be reduced while maintaining a constant output level if they adopt the most efficient technology to boost the technical efficiency index for each category of the proposed banking activities.

In Table 9, the BCC model is established, and the scale efficiency scores are computed; also, the DEA is repeated with non-increasing returns to scale, and the efficiency scores are compared. If the score for a particular DMU under the BCC equals the non-increasing returns to scale score, then that DMU must be operating under decreasing returns to scale. If the score under the BCC is not equal to the non-increasing returns to scale score, then the DMU is operating under increasing returns to scale (Avkiran, 2001).

Table 9 shows the rate of the CRS, the increasing returns to scale (IRS), and the decreasing returns to scale (DRS) for the different kinds of banking efficiency factors with the input and output-oriented analysis between 2002 and 2013. As shown in Table 9, in terms of the input-oriented analysis, Banks 1, 3, 4, 6, 7, and 12 have CRS completely for the overall banking efficiency factors during the relevant period. However, the results of the interest-based factors are also the same except for Bank 7, and none of the banks have only one type of return to scale for the non-interest based factors in the efficiency trends.

The results show that deposit banks are mostly scale-efficient between 2002 and 2013. While the operation of most banks increases under IRS for non-interest based factors, IRS with interest-based factors rose especially for Banks 8, 9, 10, and 11 during the period, implying that they could gain efficiency by increasing in size using non-interest based and partly interest-based activities. Another finding emerging from the study is that the operation of the banks increases under DRS with the non-interest based determinants of the output-oriented analysis. Thus, strategies for maximizing the profits of deposit banks may be considered to obtain efficiency for non-interest based activities.

Table 10 presents the input and output-oriented average efficiency scores of Turkish deposit banks using the CCR and BCC models. In 2002 and 2004, the banking sector did not have an efficiency of 100% in any banking activity or model. However, the banks obtained the maximum levels of efficiency of 100% by the year 2012.

The findings demonstrate that the banking sector covering Turkish deposit banks quoted on the *BIST* has efficiency results similar to the proposed banking input/output factors in terms of input and output-oriented analysis. The result is evidence that there is no reason to select an input or output-oriented strategies to improve banking efficiency. Nevertheless, the efficiency scores for the banking sector under the BCC model give more complete results than the CCR model for overall banking efficiency factors during 2002–2013. This outcome indicates that the Turkish banking sector mostly has pure technical efficiency, which measures the degree to which banks utilize their resources under exogenous factors.

The banking sector has the worst efficiency scores for the non-interest based factors of banking activities between the years 2002 and 2013. This issue could be explained because the banking sector in Turkey may not have been ready to utilize other operating income and because there may still have been some shortcomings in using different banking operations, such as alternative distribution channels, to increase profits in recent days.

5. Concluding remarks and implications

The combination of risk-based factors in the financial system, such as the financial distress of the banking industry, the solvency problem, market liquidity, the transmission of risk from the advanced economies to emerging markets, unemployment, weaker growth, and the decline in cross-border lending still threatens economic activity across borders. The risk creating mechanisms within the financial system itself challenge decision-makers to develop and implement effective business strategies aimed at boosting corporate performance and profitability.

Concerning the related studies, our study contributed to the body of knowledge in the following ways. The first distinguishing feature of our study is the hybrid model developed for the research and the broad scope of the study. A significant number of efficiency measurement models and analyses used in recent studies have been based on the DEA only. Our study employs a hybrid methodology that combines DEA with FHP within a fuzzy environment for more realistic and reliable analyses. Another contribution of our study is the provision of novel decision-making tools to decision makers in the banking sectors for assessing the trends of banking efficiencies in complex and dynamic situations. In this context, bank managers (i.e., decision makers) who use the proposed hybrid model in their strategic planning process will be more proactive by scoring their efficiency levels before developing the banking strategies.

The empirical results demonstrated that the technical efficiency scores of the deposit banks for the overall factors are over 85% between 2002 and 2013. All of the banks have 100% technical efficiency in the years 2008, 2011, and 2012 following the crisis. The results for pure technical efficiency for the overall banking factors show that the deposit banks have better efficiency results than their technical efficiency scores between 2002 and 2013. Only Banks 9 and 11 in 2002, Banks 10 and 11 in 2003, and Bank 9 in 2013 have pure technical efficiency scores less than 100%. The results of the scale and technical efficiency are closely similar in the studied period. Moreover, the pure technical efficiency results are more remarkable than the technical efficiency for the overall banking activities. This illustrates that managerial skills could contribute more actively, and the resources are used under exogenous factors in the development process of banking efficiency (Assaf, Barros, & Matousek, 2011; Kauko, 2009).

The results show that total deposits/total assets are the most crucial factor, whereas permanent assets/total assets have the weakest importance among the input set of banking efficiency. However, net profit (losses)/total shareholders' equity has emerged as the highest priority of banking efficiency outputs as non-interest income/total assets are the least important factor of overall banking operations. It seemed to be a clear evidence that the consumers of commercial banks should be encouraged to save their money (Holod & Lewis, 2011) and long term-investments could not be solely an effective policy for the banking industry (Qin & Song, 2009). Moreover, banks should also generally focus on the overall performance results, and this finding is coherent with the outcomes of Mukherjee, Nath, and Pal (2003) and Barathi Kamath (2007).

Primarily, efficiency strategies in the banking industry are usually related to the maximization of profits with the overall banking operations, but the overall activities of banks are equally sensitive to the input and output-oriented analysis (Das, Nag, & Ray, 2005). Additionally, the other operational activities of banks should also be widened and diversified for the long term efficiency development (Avkiran, 2011).

Based on the findings of the study, it is construed that the efficiency results of Turkish deposit banks vary based on their technical efficiency scores during the recession. The level of competition, the structural changes, the adoption of new technology, and ownership structure are some of the components which shape the nature of significant banking activities.

Finally, based on the results, it is plausible to conclude that neither interest-based banking factors nor non-interest based factors are components of efficiency that are sufficient to produce high-efficiency scores in the Turkish banking sector. Therefore, the findings suggest that banks could improve their performance levels based on enhanced technical efficiency scores if their pure technical efficiency is increased sustainably.

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