

RESEARCH

Open Access



Bank intermediation efficiency and liquidity risk in Egypt: a two-stage non-parametric analyses

Rania Pasha^{1*}

Abstract

This is a pioneering study that undertakes a comparative analysis assessing the annual intermediation efficiency of public versus private banks in Egypt. Moreover, liquidity risk is a major threat facing banks in their efforts to sustain financial stability. Thus, this study is the first to model the determinants of liquidity risk in public and private banks in Egypt while examining the impact of banks' intermediation efficiencies on their liquidity risk levels. The study employs advanced nonparametric econometric approaches on a sample of Egyptian public and private banks from 2014 to 2022. The data envelopment analysis is used in estimating banks' intermediation efficiency scores, while the quantile regression analysis is applied to examine the impact of bank intermediation efficiency on liquidity risk under different liquidity risk quantiles. The findings indicate that public banks show consistent superiority in terms of their financial intermediation efficiency levels compared to private banks. Moreover, the paper findings demonstrate the negative significant relationship between bank intermediation efficiency and liquidity risk while highlighting the higher significant positive impact of intermediation efficiency on reducing the liquidity risk of banks that are characterized by undertaking high liquidity risk levels. Furthermore, contrary to general assumptions, this study's findings demonstrate that the significance of micro- and macro-level determinants of a bank's liquidity risk is dependent on its prevailing liquidity risk level. Hence, the positive impact of equity capital, asset concentration, size, and growth in gross domestic product and the negative effect of asset quality on bank liquidity risk vary under banks' different liquidity risk quantiles.

Keywords Emerging markets, Bank efficiency, Liquidity risk, Quantile regression, Data envelopment analysis, Intermediation efficiency

Introduction

The banking sector plays a crucial role in serving as an intermediary between those with surplus funds, net savers, and those in need of capital, net borrowers. Additionally, banks, entrusted with the safekeeping of individuals' most liquid asset, cash, have significant influence over

a nation's economy. Consequently, the examination of banking sector efficiency has gathered considerable attention from scholars, policymakers, and researchers.

To assess the efficiency of a banking system within a market, it is imperative to benchmark the performance of banks operating in that market. Presently, financial regulators frequently employ financial ratios derived from accounting data to assess banks. However, financial ratio analysis has limitations. It necessitates the evaluation of each ratio individually against a set of benchmark ratios, assuming constancy in all other variables and appropriateness of the selected benchmarks for comparison.

*Correspondence:

Rania Pasha
rania.pasha@bue.edu.eg

¹ Business Department, Faculty of Business Administration, Economics and Political Science, The British University in Egypt, Suez Desert Road, Al-Sherouk City, Cairo 11837, Egypt



© The Author(s) 2024. **Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

A more robust alternative assessment for bank efficiency is the data envelopment analysis (DEA). DEA is a nonparametric technique that conducts efficiency analysis through incorporating banks' multiple inputs and outputs; thus, uncovering relationships that might remain hidden with other methodologies [17]. An additional advantage of DEA lies in its capacity to analyze and quantify the sources of inefficiency for each assessed bank [30]. Therefore, the use of DEA for evaluating the efficiency of various banks is widespread within various countries.

In the last two decades, there is scarcity of studies examining bank efficiency using DEA in the Egyptian market. The Egyptian banking industry has witnessed a crucial reform phase culminating in a new era of banking digitalization during these two decades [13, 34]. Nevertheless, the impact of these recent transformations on banks' efficiency levels remains unexplored, suggesting a significant gap in the finance literature. In addition, the Egyptian banking industry has distinct bank ownership distributions. Egyptian banks fall into three categories based on ownership: public sector, private and joint venture, and foreign. Egypt's public sector commercial banks constitute a significant portion of total bank loanable funds transactions, maintain close ties with state-owned enterprises, and hold over 50% of total bank assets [20]. Thus, the banking sector in Egypt exhibits high ownership concentration, whereas private banks, in the past, played a less dominant role in the loanable funds market, concentrating on trade-related financial services. Recently, private banks have diversified their financial services to attain high intermediation efficiency by expanding into retail services, especially retail loans [20]. Despite the transformation of private banks' financial services, there exists a notable research gap represented in the lack of research comparing banks' efficiency levels across different ownership structures in Egypt during this recent period.

This study aims to fulfill the existing gaps in the literature by employing DEA to conduct a recent assessment of banks' efficiency levels in conducting their financial intermediation role in the Egyptian market. The sample period employed in this paper spans from year 2014 to 2022, a period encompassing the second pivotal phase of the Egyptian banking reform and the ongoing era of financial digitalization. Additionally, this paper employs a sample of private and private banks to conduct a comparative analysis examining the impact of the recent transformation in the private banks' activities on their bank intermediation efficiency compared to public banks.

Due to the recent competition in the Egyptian market between public and private banks, both types of banks focus on conducting their intermediation role efficiently

which would affect their liquidity risk levels. Some studies argue that there is a trade-off between intermediation efficiency and liquidity risk arising from banks' need to convert short-term deposits to long-term loans and investments [12]. On the contrary, other previous studies claim that efficient banks are less exposed to liquidity risk due to their high capitalization levels [4]. Thus, this paper aims at assessing the impact of banks' intermediation efficiency scores on their liquidity risk while examining the bank-level and macro-level determinants of liquidity risk under banks' different liquidity risk levels.

Consequently, this paper makes several theoretical contributions to the existing body of literature. Additionally, it demonstrates practical contributions that bridge the theory-practice gap by providing empirical evidence on several theoretical concepts in the Egyptian market context. To the best of the researcher's knowledge, this study represents foundational research effort to explore banks' efficiency scores using the DEA in Egypt during the recent decade. Moreover, this study is pioneering in its examination of the latest financial sector reforms' impact on bank efficiency.

Another notable contribution of this paper lies in the comparative analysis of the efficiencies of banks across different ownership structures in Egypt. This comparison is crucial, considering the previously illustrated substantial divergence in the financial activities pursued by these banks based on ownership types. Moreover, to bolster a nation's economic growth, banks must operate with efficiency while managing their risk levels, ensuring the optimal utilization of their existing resources. Thus, this paper's findings that demonstrate how banks' improved efficiency scores affect liquidity risk would provide further valuable theoretical and practical insights. Such information assists banks in solidifying their financial structures within the overall financial system and addressing any identified weaknesses [9]. Additionally, this study compares the liquidity risk determinants across banks with various levels of liquidity risk.

Therefore, this study formulates a managerial decision matrix to ascertain the relative positioning of the sampled banks while identifying the impact of this positioning on their liquidity risk levels. Thus, managers of the examined banks could measure their banks' relative efficiency level, evaluate past strategies, and spot the potential improvement capabilities and the potential areas that can enable them to exhibit differential performance while attaining low liquidity risk levels. Additionally, this paper's findings would have several policy implications, enabling policy-makers to devise appropriate strategies and guide banks toward enhanced overall efficiency, particularly in the realm of profitability and risk management.

This paper continues with section “[Literature review and hypotheses development](#),” which presents the theoretical framework, reviews the relevant research, and presents the research hypotheses. Section “[Data and methodology](#)” discusses the applied methodology and details regarding the data employed in this study. Section “[Research results and discussion](#)” presents the empirical results and the corresponding discussions. Finally, Section “[Conclusion](#)” provides the conclusion, research limitations, and recommendations for future studies.

Literature review and hypotheses development

Bank efficiency measurement using DEA: Theoretical review

Financial markets became very competitive in both developed and emerging markets. Thus, bank managers and investors focus on determining effective techniques to evaluate banks’ efficiency levels and plan their forthcoming decisions. Moreover, attaining efficiency facilitates the introduction of new products or services in the banking industry, as it helps to improve any outdated operational processes [1].

Profitability is not considered the only indicator of bank efficiency. Essentially, the effectiveness of reducing bank inputs while sustaining its levels of output is a more robust indicator of efficiency. Thus, to increase efficiency, bank managers must effectively manage both input and output aspects [23]. According to Beccali et al. [11], banks with high efficiency levels are capable of raising low-cost capital and achieving higher profitability, thus, reflecting enhanced financial performance.

Parametric and nonparametric methods are the two main approaches employed in the literature to assess bank efficiency in managing its inputs and outputs. Nevertheless, parametric methods have some limitations. A parametric model requires the specification of an explicit functional efficient frontier, on which efficient banks are positioned. Additionally, parametric models prove their effectiveness only when one input and output or multi-inputs and one output are employed. Moreover, a large number of sample observations is required for reliable results using bank efficiency measurement parametric methods [32]. In contrast, nonparametric methods do not require large samples and are used to assess banks using several inputs and outputs. Therefore, nonparametric models, especially DEA, are the most commonly employed methods for measuring bank efficiency in the current literature.

DEA is a nonparametric technique used to efficiently analyze a decision-making unit (DMU). Charnes–Cooper–Rhodes (CCR) DEA model was first used by Charnes et al. [14] and ever then it has been frequently used in all industries to evaluate the efficiency of firms

and banks. Subject to the desired decision-making, DEA technical efficiency models can be input- or output-oriented. The DEA technique can assess the capability to maximize profits and output levels while maintaining input variables, or the achievement of given outputs through minimizing the input prices and costs. The former is input-oriented, and the latter is output-oriented [26].

Moreover, DEA is considered a valuable technique, as it transforms inputs into outputs while comparing a bank’s efficiency with other banks operating in the same market [43]. Thus, DEA technique assesses a bank’s efficiency compared to other banks and determines the primary causes for inefficient management. Additionally, based on the DEA technique, no functional form estimation is required to evaluate a bank’s production function. Moreover, DEA can precisely measure the performance of a bank system in terms of numerous inputs and outputs. Furthermore, for low-performing banks, the DEA technique provides benchmark data of peers that is required to enhance their poor performance [31].

Employing DEA to examine bank efficiency: Empirical evidence

Numerous studies in the existing literature have investigated the efficiency of banks across various emerging markets by employing DEA. These studies have systematically compared the performance of public, private, and foreign banks within the dynamic landscape of the banking sector. Given the pivotal role of banking systems in nations and the ever-evolving nature of this sector, research papers examining this topic have been recurrent from the 1990s through 2023 in emerging and developed countries with recent focus on emerging markets.

Noulas [36] utilizes both the DEA model and the conventional method to examine the impact of banking deregulation on Greek banks owned by the public and private sectors for the period 1993–1998. Input variables included interest and non-interest expenses, while output variables encompassed interest and non-interest revenues. The findings indicate that public banks exhibit lower efficiency compared to private banks, and this efficiency gap expands over the studied sample period.

Additionally, Zhu et al. [44] investigates the operational efficiency, productivity, and disparities in operational efficiency and productivity among private, public, and foreign banks in Pakistan from 2006 to 2017. The empirical findings show that foreign banks have higher average technical and pure technical efficiency scores compared to local banks. Nevertheless, local banks were comparatively better in terms of the mean scale efficiency score compared to foreign banks. In addition, public

sector banks exhibited better performance than the private banking industry in this regard.

Moreover, an investigation into the Indian banking system by Akhtar et al. [6] indicates that Indian banks, in general, were on a constant efficiency trend during the period of study from 2015 to 2018. Additionally, the study reveals that the efficiency scores of public banks are higher than private and foreign banks. Beyond the sector-wide analysis, the study delves into individual bank performance for a more detailed examination. At the individual bank level, the findings indicate that state-owned banks demonstrate the highest efficiency, while foreign banks come next, followed by private banks that are reported to be the least efficient.

In another study conducted by Gökgöz et al. [23], utilizing data from Turkish banks spanning the years 2017 to 2021. The study aims to analyze both the profit efficiency and productivity of Turkish banks. The findings highlight that the examined banks did not demonstrate profit efficiency during the period under investigation with the exception of two out of three public banks that attained resource efficiency. Additionally, the study observed that, on average, resource efficiency was higher than profit efficiency in Turkish banks.

Additionally, in the period from 2013 to 2019, a comparative analysis involving 40 Indian banks, comprising 21 public sector banks and 19 private sector banks, conducted by Kumar and Kar [30], revealed distinctive efficiency patterns between public and private banks. Private banks demonstrated greater efficiency in the profitability stage, attributed to their enhanced income-generating capabilities. Conversely, public banks exhibited higher efficiency in intermediation, surpassing their private counterparts.

In the context of the Arab countries, some studies assess bank efficiency employing DEA analysis, such as Nia et al. [35] that evaluates efficiency of private and public banking system in Iran for the period 2006 to 2010. The results show the inefficiency of the government banking system opposed to the higher efficiency levels of private banks. In Egypt, on the other hand, a noticeable dearth exists in the literature concerning comparative analyses of the efficiency between public and private banks, with only two exceptions in previous studies. To illustrate, Poshakwale and Qian [39] explores the repercussions of financial reforms on the competitiveness and production efficiency of the banking sector, as well as their short-term and long-term effects on economic growth in Egypt from 1992 to 2007. The findings indicate a positive and substantial impact of the reforms on both competitiveness and production efficiency. Additionally, the evidence reveals a general pattern, wherein state-owned banks exhibit lower competitiveness compared to

private banks, and foreign banks demonstrate less competitiveness compared to their domestic counterparts.

In addition, Hassan and Jreisat [25] assess Egyptian banks and the factors influencing their efficiency. They employed data envelopment analysis to gauge the efficiency levels of banks and compare their efficiency across various categories, including large, medium, and small banks, as well as foreign and domestic banks. The investigation encompassed 14 banks spanning the period from 1997 to 2013. A meticulous breakdown by banking groups disclosed that medium-sized banks exhibited the highest efficiency, with foreign banks following closely behind.

However, it is imperative to note that the sample periods employed in these studies do not encompass the recent reforms within the Egyptian banking sector. To enhance banking system efficiency, Egypt's banking industry has undergone multiple phases of financial reforms. The Central Bank of Egypt (CBE) initiated a reform program in 2004, focusing on infrastructure development and creating a more efficient and sound banking sector. The reform, carried out in two phases, reduced the number of operating banks from 61 in 2004 to 40 in 2008, while bank assets, deposits, and capital adequacy ratios all experienced significant positive changes [34].

The second phase, commencing in 2009, aimed to deepen the Egyptian banking sector, enhance efficiency, and improve competitiveness. This phase included measures to expand access to financial services, implement Basel II/III standards, and strengthen corporate governance. Later, in response to technological advancements, a new law, the Central Bank and the Banking System Law No. 194 of 2020, was enacted to address emerging financial technology changes in the financial landscape [13].

Accordingly, various reforms have significantly bolstered the resilience of the banking sector in Egypt, particularly in the aftermath of the 2008 financial crisis, the period of political instability from 2011 to 2013, and the onset of the new financial technology landscape in 2020. Moreover, over the last decade, this sector has undergone substantial transformations marked by significant shifts in interest rates, foreign exchange rates, market dynamics influenced by the COVID-19 pandemic, and the advent of the latest era of banking digitalization.

These transformations are common worldwide, as COVID-19 pandemic has caused substantial financial damages and economic crises in several developing and developed markets [2]. Thus, in the current unsteady economic atmosphere, innovation and technological developments are considered tactical and financial motivators [3]. This necessitates examining bank efficiency under Egypt's new era of banking digitalization. Accordingly,

this paper aims to fulfill this gap by conducting a comparative analysis on the efficiency of private and public banks in Egypt, spanning from 2014—representing the start of the politically stable period and including the second pivotal phase of banking reform—up to year 2022, encompassing the ongoing era of digitalization.

It is hypothesized that public banks would have higher efficiency scores compared to private banks, as the Egyptian government-owned commercial banks hold over 50% of total bank assets. In addition, the development projects, including Financial Technology (Fintech) projects implemented in Egypt are undertaken by the public sector commercial banks [13]. Thus, it is expected that public banks execute their financial intermediation role more efficiently than private banks. The following hypothesis is developed accordingly.

H1 Public sector commercial banks have higher average intermediation efficiency score compared to private commercial banks in Egypt.

The impact of bank efficiency on liquidity risk

Previous studies demonstrate the trade-off between profitability and liquidity. To boost profitability, banks pursue high risky loans and investments and sacrifice the provision on liquidity buffer [8]. Thus, attaining high liquidity would have a negative impact on bank profitability. Moreover, due to the intense competition in the banking industry, banks have been forced to boost profitability, thus, increasing their liquidity risk levels. Consequently, several studies in the literature examine the relationship between bank profitability and liquidity risk.

Most empirical studies are focused on the American context, De Nicolo [18], Imbierowicz and Rauch [27], the European context, Chortareas et al. [15], Kim [28], and Asian countries, Tan [42], Zolkifli et al. [45]. Few studies, such as Abdelaziz et al. [4] and El-Massah et al. [19], investigate the relationship between liquidity risk and bank profitability in the Middle East and North Africa (MENA) region.

Abdelaziz et al. [4] examine the relationship between liquidity risks and bank profitability within the MENA countries during the period from 2004 to 2015. Their findings state that bank profitability has a significant negative impact on the bank level of liquidity risk. They argue that more profitable banks are less exposed to liquidity risk, as they are characterized by high capitalization levels [4].

Nevertheless, El-Massah et al. [19] that study the impact of profitability on bank liquidity risk in 257 Islamic and conventional banks over the period 2009–2016 demonstrate that profitability is not a significant determinant of liquidity risk. El-Massah et al. [19] claim

that regardless of their types, high financial performance banks in the MENA region are hesitant to pursue elevated levels of liquidity risk.

Notably, these previous studies that examine the impact of banks' high financial performance on liquidity risk, employ financial ratios, such as net interest margin, return on equity, or return on assets. Although the literature is abundant on how cost, operational, and intermediation efficiencies increase bank performance in several markets, little is known about their effects on banks' risk-taking behaviors, particularly liquidity risk. Only few studies examine the impact of banks' efficiency scores on their liquidity risk levels.

Safa et al. [41] studies the impact of the cost efficiency of Islamic banks and conventional banks on their liquidity risk levels employing a sample from 16 of the Organisation of Islamic Cooperation (OIC) countries from 1999 to 2013. Their results support the positive impact of cost efficiency on liquidity risk [41]. Their findings are consistent with few studies in other markets that support the notion that banks seeking high efficiency scores tend to take more risks by providing illiquid financings [7, 8].

As far as the researcher's knowledge, there is scarcity in studies that examine the impact of banks' efficiency scores on their liquidity risk levels in the MENA region, particularly Egypt. Based on the previous literature conducted in the MENA region that measure the impact of bank financial performance on liquidity risk, banks characterized by high financial performance follow a conservative financial behavior in terms of liquidity risk taking [19]. Thus, it is argued that as a bank's efficiency score increases, liquidity risk would decrease. Additionally, banks with high intermediation efficiency scores are characterized by better capitalization, deposit, and borrowing levels which would serve as effective tools in mitigating liquidity risk. Accordingly, hypothesis 2 is developed as follows.

H2 In Egypt, banks' high intermediation efficiency scores have a significantly negative impact on bank liquidity risk.

A major contribution of this study is examining the relationship between bank intermediation efficiency and liquidity risk under different liquidity risk-taking levels. It is argued that the negative impact of intermediation efficiency on liquidity risk would be strengthened under conditions of bank high liquidity risk level taking. The enhanced benefits of high intermediation efficiency in terms of profitability and risk management tools availability are more pronounced when banks are initially at high liquidity risk levels compared to low liquidity

risk-taking banks. Hence, improvement in intermediation efficiency scores in banks with high liquidity risk levels would dramatically improve their ability to manage and mitigate liquidity risks compared to banks with low liquidity risk levels. Accordingly, hypothesis 3 is developed as follows.

H3 In Egypt, for high liquidity risk-taking banks, intermediation efficiency has a more significant negative impact on their liquidity risk levels compared to banks with low liquidity risk.

Data and methodology

Data and sample selection for DEA and quantile regression analysis

The sample period examined spans from 2014 to 2022 to incorporate the beginning of the politically stable period and the second pivotal phase of banking reform until the recent digital transformation of financial services in the banking sector on both public and private banks. Since this study conducts a comparison between public and private commercial banks in Egypt, the sparse number of public banks, 3 banks as of year 2022, poses a constraint on the sample selection of the private banks, foreign and local banks, to have a significant comparison. Moreover, the three public sector commercial banks hold above than 50% of total bank assets; hence, the study specifically targets seven private banks with the largest market shares in terms of total assets as of the end of the sample study period in 2022. Thus, this study specifically targets ten banks with the largest market share in terms of total assets as of the end of the sample study period in 2022.

In addition, this paper employs DEA to impute banks' intermediation efficiency scores. Thus, the total of employed DMUs, the studied banks, "should be at least two times higher than the sum of diverse inputs and outputs" [24], which is confirmed by other studies in the literature that employ DEA efficiency score measurement. Since three inputs and two outputs are examined in this study, the sample selected is represented in ten banks.

All bank-level data are retrieved from BankFocus database. GDP growth rates are collected from Refinitiv database, while inflation is obtained from the Central Agency for Public Mobilization and Statistics (CAPMAS).

First-stage methodology

Due to the small number of studied banks and multi-inputs and multi-outputs adopted, this study employs the DEA nonparametric method to determine their intermediation efficiency scores. DEA is better employed with small sample sizes as opposed to parametric methods that require large sample sizes to generate reliable estimates [33].

In this study, the output-oriented DEA model with a VRS is employed to analyze the intermediation efficiency scores of public and private banks operating in Egypt. Based on previous studies that examine the efficiency of banks' intermediation function, the inputs used in this study's DEA model are labor, capital, and deposits while the outputs are loans and investments. These variables are commonly used for assessing banks' intermediation efficiency levels by several previous studies. They are the core variables that banks employ to conduct their financial intermediation role [33]. The inputs and outputs employed are presented in Table 1.

The output-oriented DEA model maximizes outputs based on the prevailing input level as illustrated in Model 1. The selection of the output-oriented model is consistent with the main goals of banks due to the higher control of bank management over this model's outputs, amount of loans and investments, than its inputs [35]. Moreover, previous findings demonstrate that similarity between the efficiency scores assessed by input-oriented versus output-oriented DEA models [40].

As per model 1, the DEA employs the linear programming algorithm to fit a non-stochastic, nonparametric production frontier through calculating the efficiency of each bank (DMU) given the identical inputs and outputs variables to find the maximum ratio of weighted sum of output to the weighted sum of input (most efficient DMU). This bank is then used as a benchmark against its peers and a comparison of each bank's efficiency score is conducted. Accordingly, efficient DMUs stand on the efficient frontier line. Thus, the best-practice units are constrained to values of 1.

Constant returns to scale (CRS) for the inputs and outputs are assumed in the basic DEA model (CCR). Nevertheless, variable returns to scale (VRS) is a model introduced by Banker, Charnes, and Cooper (BCC) to determine the scale efficiency of a set of units [10]. This model has an additional convexity constraint defined by limiting the summation of the multiplier weights (*k*) equal to 1.

The BCC model evaluates whether increasing, constant, or decreasing returns to scale would boost the efficiency observed. Employing VRS, a change in the input leads to a disproportional change in the output.

Table 1 DEA variables

Inputs	Outputs
Total deposits	Total loans
Capital	Total investments
Labor expenses	

Nevertheless, in cases when banks function at their optimal size, DEA models with CRS would be more convenient. Consequently, since the main assumption required to employ CRS is not consistent with the nature of this study’s sample, DEA model with VRS is selected while using linear programming to solve the following model:

$$\begin{aligned}
 & \max \phi \\
 & s.t. \sum_{j=1}^n x_{ij} \lambda_j \leq x_{io} \quad i = 1, 2, \dots, m; \\
 & \sum_{j=1}^n y_{rj} \lambda_j \geq \phi y_{ro} \quad r = 1, 2, \dots, s; \\
 & \sum_{j=1}^n \lambda_j = 1 \\
 & \lambda_j \geq 0
 \end{aligned} \tag{1}$$

where n is the number of banks (DMUs). S is the number of output variables, while m is number of input variables. Observed output and input values are y_r and x_i , respectively. λ is the weight for outputs and inputs. Efficiency score is ϕ .

Second-stage methodology

This paper employs another nonparametric regression technique, quantile regression technique by Koenker and Hallock [29] to examine the impact of banks’ intermediation efficiency scores on liquidity risk while controlling for bank-level and macroeconomic variables. The nonparametric regression analysis is employed, as it is argued that it is more convenient in studies conducting risk analysis (Ait-Sahalia and Lo [5]). In addition, this technique mitigates any potential problems of linear parametric models, especially with small sample sizes, and provides quantile regression advantages.

Quantile regressions provide insights into the effect of the examined variables on the entire conditional distribution of the dependent variable. In this study, conditional

quantile regressions are conducted to examine the effects of the intermediation efficiency score, bank-level, and macroeconomic variables that are examined at the lower, medium, and higher quantiles of the liquidity risk variable.

The estimating model considered in this study to examine the impact of IE score on LR while controlling for bank-level and macro-level variables is as follows:

$$\begin{aligned}
 LR_{it} = & \beta_0 + \beta_1 IE + \beta_2 S + \beta_3 ETA + \beta_4 LL \\
 & + \beta_5 ROA + \beta_6 LTA + \beta_7 GDP + \beta_8 INF + \varepsilon_{it}
 \end{aligned} \tag{2}$$

Similar to Chulia et al. [16] methodology, to investigate liquidity risk across its conditional distribution, the time-series quantile model for quantile τ can be written as follows:

$$LR_{it} = \beta(\tau)xi + \varepsilon i(\tau), \tag{3}$$

where all quantile parameters are displayed in a vector $\beta(\tau) = \{\beta_1(\tau), \beta_2(\tau), \beta_3(\tau), \beta_4(\tau), \beta_5(\tau), \beta_6(\tau), \beta_7(\tau), \beta_8(\tau)\}$ and all factors in a $N \times 8$ matrix, denoted as $xi = \{IE_p, S_p, ETA_p, LL_p, ROA_p, LTA_p, GDP_p, INF_p\}$. The vector of error terms conditioned on the parameter matrix is zero, $Q\tau(\varepsilon i | xi = 0)$. The τ th conditional quantile function is as follows:

To obtain an estimate $\hat{\beta}(\tau)$ of the unknown coefficient(s) for the τ th quantile, the following function is minimized: where $\rho_{\tau}(\mu) = \mu(\tau - I(\mu < 0))$ with $0 < \tau < 1$ is a check function with asymmetric weights, which depend on the quantile selected.

Three nonparametric conditional quantile regression analyses are conducted for 0.25, 0.5, and 0.75 quantiles. In section “Research results and discussion,” the examined variables betas are presented for every quantile. Table 2 provides a brief description of the variables studied as liquidity risk determinants. Micro- and macro-level control variables that show consistent robustness as determinants of liquidity risk in previous studies in

Table 2 Quantile regression variables

Variable	Description
Liquidity risk (LR)	In (Net loans/deposit and short-term funding)
Intermediation efficiency (IE)	DEA - intermediation approach
Asset quality (LL)	Loan loss reserve/gross loans
Capital (ETA)	Equity/total assets
Profitability (ROA)	Net income/total assets
Size (S)	In (Total assets)
Asset concentration (LTA)	Total loans/total assets
Growth in gross domestic product (GDP)	Real GDP growth rate
Inflation rate (INF)	Consumer Price Index- headline inflation rate

Table 3 Intermediation efficiency scores of Egyptian banks (2014–2022) by ownership type

DMU	2014	2015	2016	2017	2018	2019	2020	2021	2022
<i>Panel A: public banks</i>									
Banque Du Caire	0.9836	0.7255	0.7408	0.8738	0.3642	0.7425	0.7210	0.7658	0.6590
National Bank of Egypt	1	1	0.7449	0.7648	0.8496	1	0.9014	1	1
Banque Misr	1	1	1	1	0.5769	0.9866	0.9368	0.5475	0.8362
Mean	0.9945	0.9085	0.8286	0.8795	0.5969	0.9097	0.8531	0.7711	0.8317
<i>Panel B: private banks</i>									
Commercial International Bank	1	1	0.9461	1	1	1	1	1	0.9624
QNB Alahli Bank	0.7256	0.8590	0.7218	0.5789	0.6137	0.5707	0.5476	0.7297	0.7556
HSBC Bank Egypt S.A.E	0.7036	0.8485	0.5750	0.5753	0.6476	0.9064	0.9562	0.9867	0.8698
The National Bank of Kuwait-Egypt S.A.E	0.9635	0.9022	0.7858	0.399	0.6339	0.7150	0.5435	0.6904	0.5895
Emirates National Bank of Dubai S.A.E	0.6104	0.5385	0.6792	0.4507	0.3915	0.5213	0.4381	0.6103	0.4631
Egyptian Gulf Bank S.A.E	1	0.7730	0.8205	0.6673	0.7071	1	1	1	1
Al Ahli Bank of Kuwait-Egypt	0.1184	0.3309	0.4143	0.3144	0.3373	0.3943	0.5127	0.6867	0.4983
Mean	0.7316	0.7503	0.7061	0.5694	0.6187	0.7297	0.7140	0.8148	0.7341

developed and emerging markets are examined as control variables [8, 21, 39]. The examined bank-level and macroeconomic variables are measured as follows.

Research results and discussion

Intermediation efficiency scores of public versus private Egyptian banks

Table 3 displays the efficiency scores of the ten examined banks for the period from 2014 to 2022. The results reported show an individual comparison of the efficiency measures between government and private banks. In general, public banks are more efficient in implementing

their intermediation function than private banks. This is evident in almost every examined year except for two private banks, Commercial International Bank and Egyptian Gulf bank. These two private banks consistently score high efficiency scores in all examined years, as they represent two of the oldest and solid private banks in Egypt.

Figure 1 plots the annual means of the examined public versus private banks intermediation efficiency scores for the period from 2014 till 2022. Public banks show consistency in their high efficiency throughout the examined period except for year 2018. There was a significant drop in the IE score of public banks this year. Year 2018

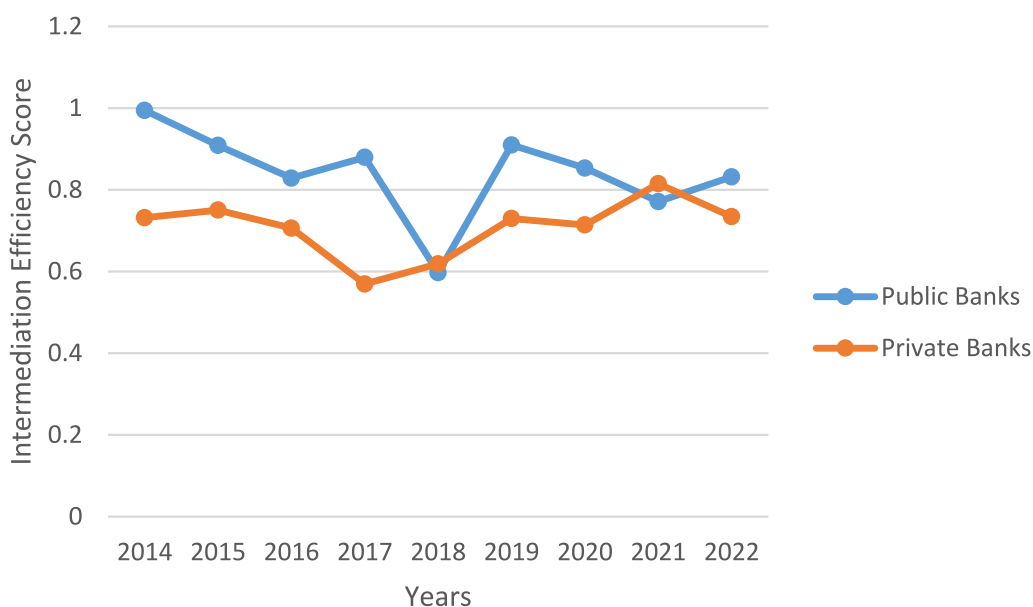


Fig. 1 Mean intermediation efficiency scores of public versus private banks

witnessed the inauguration of its economic and social reform program that incorporated several developmental projects in different Egyptian governorates. As discussed in the literature review section, Egyptian public banks play a key role in undertaking the government development projects. Consequently, the low efficiency level of public banks in this year can be justified by the introduction of additional operational complexities and administrative burdens, potentially affecting the efficiency and effectiveness of the banks’ operations and diverting them from their main intermediation financial activities. Nevertheless, this negative impact was only on the short-term level, as they regained their efficiency the following year.

Moreover, as illustrated in Fig. 1, the means of public banks efficiency scores are always higher than their private banks counterparts for every examined year. This is further confirmed by the significant mean t tests of the difference in the efficiency scores of public versus private banks with both parametric and nonparametric methods, as illustrated in Table 4. Thus, this research finding supports hypothesis 1 and is consistent with previous studies in other emerging markets, such as Patra et al. [38] in India. Patra et al. [38] states that public banks have played a lead role compared to private banks in terms of achieving business efficiency, a similar efficiency measure to the intermediation efficiency examined in this study.

On the other hand, the consistent superiority of public banks in their high efficiency levels compared to private banks is inconsistent with the findings of Poshakwale and Qian [39] in Egypt. This discrepancy might be attributed to the difference in the focus of both studies. Poshakwale and Qian [39] concentrate on examining the efficiency of banks in attaining profitability and managing costs, while this study focuses on their efficiency in fulfilling their main function, which is financial intermediation. Thus, the findings of this research indicate the efficiency of public banks in their financial intermediation role,

independent of their profitability and cost management efficiency levels.

Furthermore, there is inconsistency in the higher average efficiency scores of public and private banks compared to their counterparts in previous research findings conducted in Egypt. Previous studies, such as Poshakwale and Qian [39] and Hassan and Jreisat [25], estimate banks’ efficiency scores in Egypt for the periods from 1997 till 2013, excluding the second pivotal phase of banking reform and the ongoing era of digitalization. Hence, the recent higher efficiency levels of banks in Egypt support the significance of this research findings to materialize the impact of the new banking reforms and bank digitalization strategies on bank performance. Notably, the positive impact of the recent banking reforms and digitalization era on bank performance is further evidenced in this research findings consistent with previous studies in the Egyptian context [37].

Moreover, although public banks have played a lead role in applying their financial intermediation role compared to private banks, the private banks are improving their efficiency continuously over time and able to reach on par with the public banks, especially in the recent years. This signals the contribution of this study’s findings that demonstrate the positive impact of private banks recent diversification in financial services on their efficiency levels.

Additionally, both private and public banks show relatively high efficiency scores in the recent examined years although it includes high unstable economic conditions marked by significant changes in interest rates, fluctuations in foreign exchange rates, and shifts in market dynamics impacted by the COVID-19 pandemic. These findings support the positive and significant impact of the substantial progress in bank digitalization and the recent banking reform steps on enhancing the financial intermediation role of banks. Thus, this study is a pioneer in examining the impact of the significant development in bank digitalization on banks’ ability to withstand negative economic conditions.

Table 4 Difference in the intermediation efficiency scores of public versus private Egyptian banks

Statistic	Intermediation efficiency score
Mean for public banks	0.8415
Mean for private banks	0.7076
Difference	0.1339
t-stat. for the difference	3.0220
Prob > t	0.0081
z-stat. for the difference	2.310
Prob > z	0.0209

Impact of bank intermediation efficiency score on liquidity risk: Nonparametric quantile regression results

The descriptive statistics for the variables under study are summarized in Table 5. Liquidity risk has a high mean value and high standard deviation indicating the great deviation in the level of liquidity risk in the examined banks. This supports the employment of quantile regression to capture the determinants of liquidity risk and the impact of bank intermediation efficiency score under the different quantiles of liquidity risk. Similarly, LTA shows high mean and standard deviation values highlighting the variations in the examined banks assets concentration.

Table 5 Descriptive statistics

Measure	LR	IE	LL	ETA	ROA	S	LTA	GDP	INF
Mean	55.6533	0.7478	5.4097	9.0499	2.1200	19.4117	38.3972	4.4586	13.1140
SD	12.5712	0.2201	2.9075	2.6549	1.4671	1.2594	10.1590	1.1196	6.7755
Minimum	30.4466	0.1184	1.1648	4.9183	-1.1531	16.6560	19.2671	2.9159	5.4280
Maximum	86.4239	1	14.8514	14.5733	11.1701	22.8913	57.7850	6.5878	23.2690

This table reports the mean, median, standard deviation (Std. dev), minimum and maximum values of the examined variables.

Table 6 Correlation matrix

	LR	IE	S	ETA	LL	ROA	LTA	GDP	INF
LR	1.0000								
IE	-0.8077***	1.0000							
S	-0.3271***	0.4750***	1.0000						
ETA	0.0278***	-0.1821*	-0.2214**	1.0000					
LL	-0.3078***	0.3822***	0.1094	0.0869	1.0000				
ROA	0.1796*	-0.1426	-0.1901*	0.6077***	-0.0028	1.0000			
LTA	0.6528***	-0.6777***	-0.3590***	0.2908***	-0.4507***	0.1188	1.0000		
GDP	0.0189	-0.0879	0.2108**	-0.0775	-0.1243	0.0990	0.0281	1.0000	
INF	-0.0093	-0.1110	-0.0058	-0.2936***	-0.0150	0.1644	-0.0642	0.3912***	1.0000

***, ** and * denote significance at 1%, 5% and 10% levels, respectively

This is consistent with this research argument, discussed in the literature review section, regarding the difference in the concentration of public versus private banks in the loanable funds market. Consequently, LTA is expected to have high significant impact on the liquidity risk of the examined banks.

Pearson correlation analyses between all variables under study are conducted. The correlation matrix is presented in Table 6. IE and all bank-level control variables show high significant correlations with LR, except the macroeconomic variables. Thus, the employment of this research regression model is validated to examine the impact of IE on LR. The correlation coefficients for the tested variables are below the threshold of 0.9, and the value of the variance inflation factor (VIF) test does not exceed 5; thus, the problem of multicollinearity is not present in the employed regression model.

Equation 1 is estimated for 0.25, 0.5, and 0.75 quantiles. The results are illustrated in Table 7 in Panels A, B, and C. Hypothesis 2 is supported by the presented statistically significant negative nonparametric effect of intermediation efficiency on liquidity risk at all quantiles of interest at 99% significance level. In addition, the negative linear impact of IE on LR is evident in Fig. 2. Thus, the negative impact of IE on LR stated in this study is evidenced employing both parametric and nonparametric approaches. This is consistent with

previous findings stating the linear negative impact of bank high financial performance on liquidity risk, such as Abdelaziz et al. [4] within the MENA countries. This can be attributed to the more conservative behavior of efficient banks in terms of liquidity risk taking [19].

Moreover, the coefficient values of IE increase as the LR quantiles increase as illustrated in Table 7 and Fig. 2. These findings support hypothesis 3, as IE shows higher negative impact on the liquidity risk of banks characterized by high liquidity risk-taking levels. The estimated coefficient values of IE for the 0.25, 0.5, and 0.75 quantiles are -29.8336, -36.2468, and -48.5028, respectively.

The significance of the other examined bank-level variables and macroeconomic variables as determinants of LR are not consistent across all the examined quantiles. For the 0.25 quantile, the ETA and LTA have positive significant impact at 99% significance level on LR in addition to the significance of the negative effect of LL on LR at 95% significance level and positive impact of GDP on LR at low significance level of 90%. For the 0.5 quantile, S, ROA, and LTA show positive significant impact on LR at 99% significance level. For the 0.75 quantile, LL has a significant negative impact on LR at 95% confidence level.

The significant impact of S, ROA, LTA, ETA, LL, and GDP on LR in different liquidity risk quantiles is consistent with the findings of previous studies that state

Table 7 Quantile regression results

	Estimate	SE	t-value	Pr(> t)
<i>Panel A: 0.25 quantile regression parametric coefficients</i>				
(Intercept)	43.7816	7.5311	5.81	0.000
IE	-29.8336	1.8273	-16.33	0.000
S	0.1855	0.3140	0.59	0.556
ETA	0.8082	0.1725	4.69	0.000
LL	-0.2496	0.0946	-2.64	0.010
ROA	0.3882	0.2497	1.55	0.124
LTA	0.4535	0.0474	9.57	0.000
GDP	0.6399	0.3569	1.79	0.077
INF	-0.0658	0.0630	-1.04	0.300
R ²	63.75%			
<i>Panel B: median regression parametric coefficients</i>				
(Intercept)	27.2196	10.7254	2.54	0.013
IE	-36.2468	3.7212	-9.74	0.000
S	1.8840	0.5021	3.75	0.000
ETA	0.2352	0.3159	0.74	0.459
LL	-0.2583	0.2207	-1.17	0.245
ROA	1.5414	0.5391	2.86	0.005
LTA	0.4199	0.0810	5.18	0.000
GDP	-0.4729	0.5437	-0.87	0.387
INF	-0.0325	0.1018	-0.32	0.751
R ²	59.8%			
<i>Panel C: 0.75 quantile regression parametric coefficients</i>				
(Intercept)	81.5221	12.7329	6.40	0.000
IE	-48.5028	5.7175	-8.48	0.000
S	0.8285	0.7165	1.16	0.251
ETA	0.5550	0.4178	1.33	0.188
LL	-0.6956	0.2821	-2.47	0.016
ROA	-0.2289	0.6535	-0.35	0.727
LTA	-0.0197	0.1017	-0.19	0.847
GDP	-0.5813	0.6887	-0.84	0.401
INF	0.0135	0.1454	0.09	0.926
R ²	58.61%			

their significance as liquidity risk determinants in other markets, such as [8] and in the Mena region, such as Ghenimi et al. [21]. The additional examinations conducted in this paper reveal the difference in the significance of some of these variables in banks with high versus low liquidity risk levels. LTA shows significant positive impact on LR in the 25th and 50th quantiles, as banks with low liquidity risk levels are expected to increase their liquidity risk levels when increasing their ratio of loans to assets. On the other hand, banks with high liquidity risk levels would be hesitant to further undertake high liquidity risk while increasing their loans to assets. Thus, LTA does not have

significant impact on LR for banks in the higher liquidity risk quantile. Moreover, LL has a significant negative impact on LR in the 25th and 75th quantiles, while its estimated coefficient value is higher under the 0.75 quantile. The negative impact of increased LL, which reflects a rise in credit risk, is expected to be more pronounced in banks that are already suffering from high liquidity risk levels.

Remarkably, the nonparametric impact of the significant examined independent variables on liquidity risk within every quantile are depicted in Figs. 3, 4, and 5. The graphs plotting the results of this study under different quantile regressions display the development of the probable impacts of the examined bank-level and macroeconomic variables and liquidity risk while presenting the directions of these effects. The estimated effects under each examined quantile of the bank liquidity risk are captured by the solid blue line accompanied by the associated 95% confidence intervals of the quantile regressions, shaded in gray.

As illustrated in the figures, the relationship between liquidity risk and some of the significant variables within each quantile are not the same across the examined quantiles. For instance, the effect of asset concentration, LTA, on LR is decreasing at the 25th percentile. However, it exhibits a more volatile nonparametric behavior at the 0.5 quantile as it decreases and then increases at a certain level while keeping the same positive direction with LR.

Consequently, the findings of this study contribute to the existing literature, as it is the first study to demonstrate the inconsistency in the robustness of banks' liquidity risk determinants for banks with different liquidity risk levels. Thus, bank managers should consider their existing liquidity risk level when estimating the impact of bank-level and macro-variables on increasing their liquidity risk.

Conclusion

Theoretical and practical contributions

The assessment of bank efficiency has been widely analyzed in several developed markets; nevertheless, investigation on this topic in developing countries, particularly African countries and the MENA region, is relatively scarce. Therefore, this research contributes to the existing literature by fulfilling the existing gap and conducting a comparative study examining the efficiency score of public and private banks in Egypt, one of the highly reforming economies in Africa and the MENA region. Public banks show consistent superiority in regard to their financial intermediation efficiency levels opposed to private banks. This can be attributed to the argument

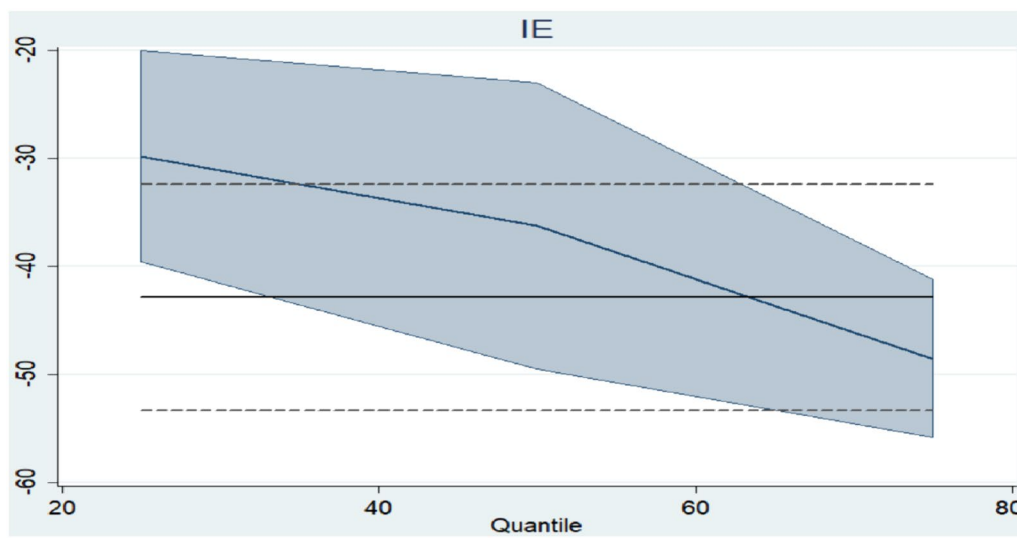


Fig. 2 Nonparametric quantile effects of bank intermediation efficiency score on bank liquidity risk. This figure displays the impact of bank intermediation efficiency score on liquidity risk. The linear impact is presented by the solid black line and two dotted lines displaying the 95% confidence level. The solid blue line with the gray-shaded area presenting the confidence intervals of the quantile regressions displays the impacts of intermediation efficiency score under different quantiles of the bank liquidity risk.

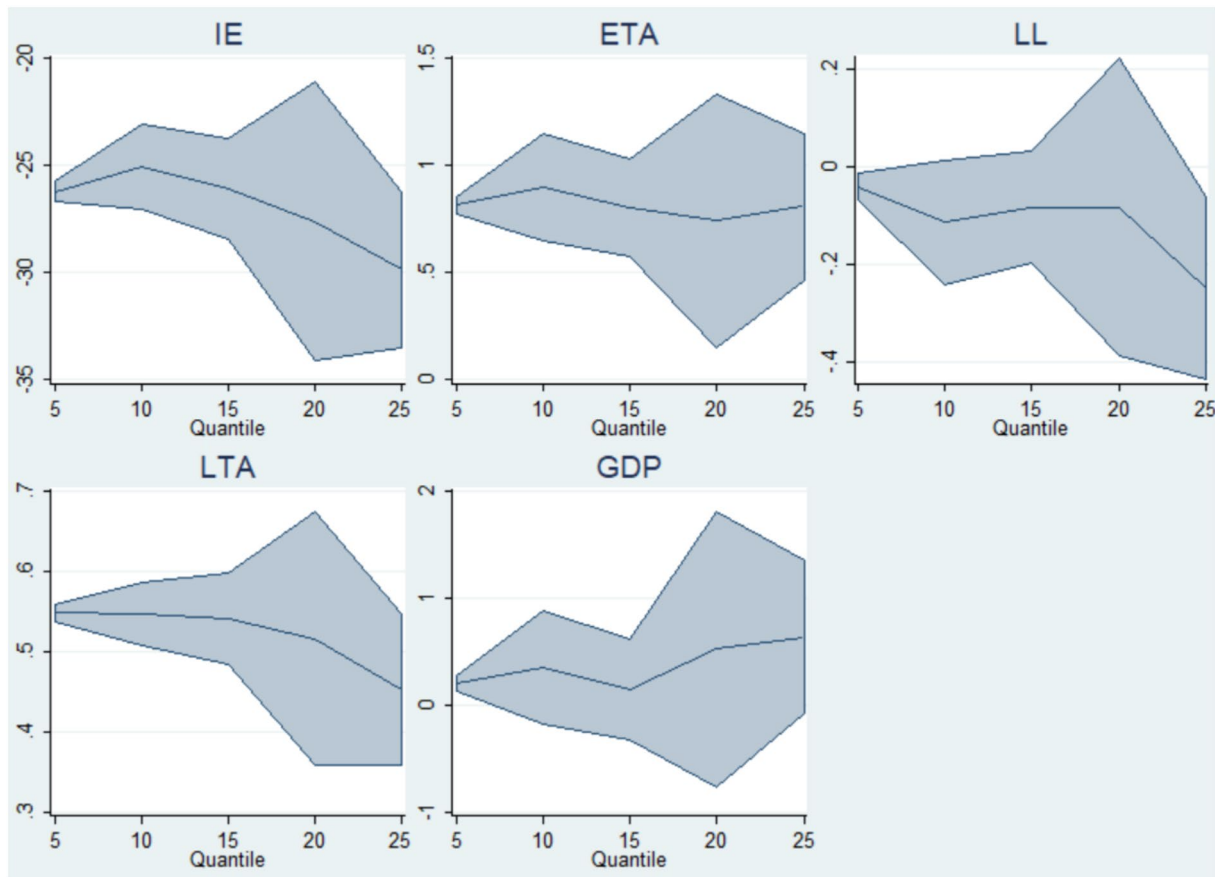


Fig. 3 Nonparametric 25th quantile effects on bank liquidity risk

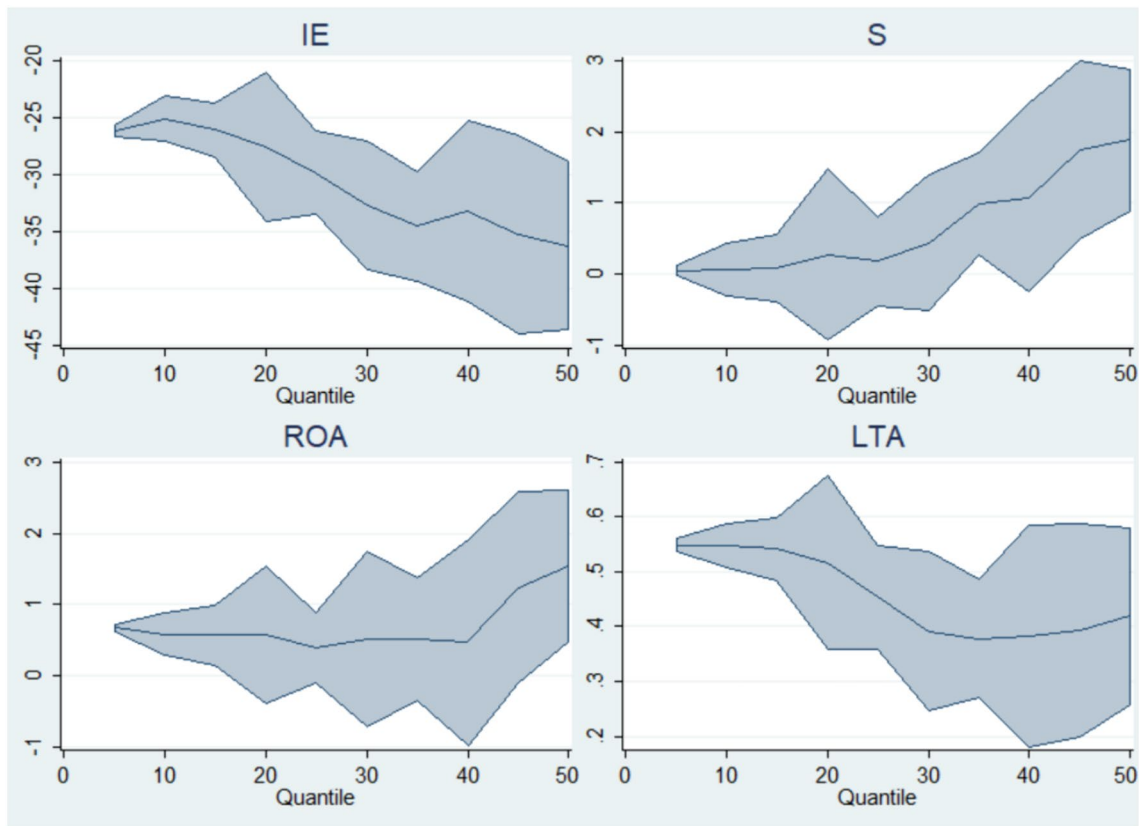


Fig. 4 Nonparametric 50th quantile effects on bank liquidity risk

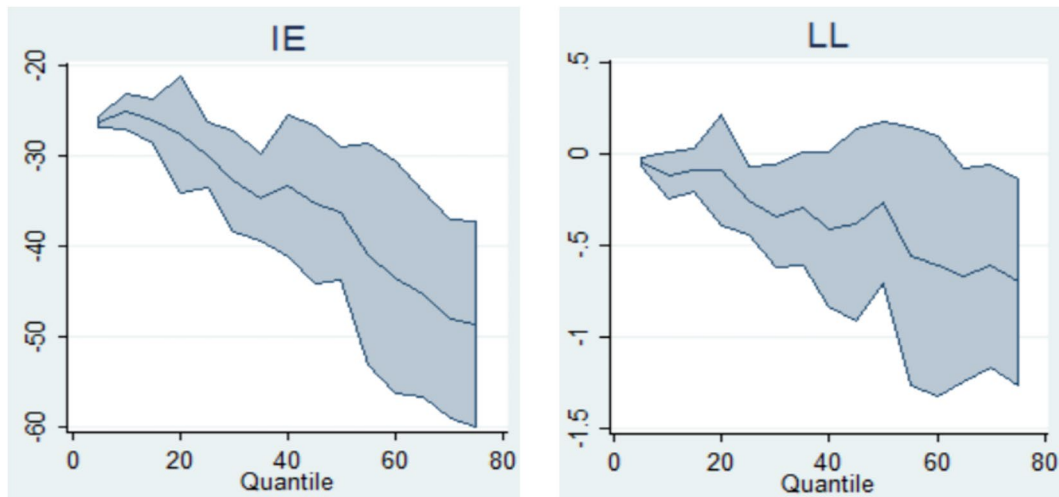


Fig. 5 Nonparametric 75th quantile effects on bank liquidity risk

that public banks are financing most of the main country’s development projects, including Financial Technology (Fintech) projects, in addition to holding over 50% of total bank assets in Egypt.

Moreover, this study adds another contribution to the literature by representing the foundational research effort to explore bank efficiency in Egypt during the recent decade. The study’s findings provide new evidence regarding

the positive impact of the latest financial sector reforms and bank digitalization era on improving the efficiency levels of both government and private banks.

Furthermore, the paper's findings demonstrate the efficiency score of each of the largest banks in Egypt annually which serve bank managers and investors to compare the performance of banks. This supports investors to efficiently formulate their investment decisions. Additionally, highlighting each bank's position supports bank managers in assessing the effectiveness of their previous managerial decisions while emphasizing the importance of efficiently planning for their future decisions to manage their banks' intermediation roles.

The paper has further contributions in bank risk management framework. Bank liquidity risk is a complex and consequential risk, accumulated from several types of risks such as credit risk, interest rate risk and operational risk. Therefore, this study adds another contribution to the existing literature by examining the impact of bank intermediation efficiency on liquidity risk in the Egyptian market. The paper findings demonstrate the negative significant relationship between bank intermediation efficiency and liquidity risk. This is consistent with this paper's argument that banks with high intermediation efficiency scores are characterized by better capitalization, deposit, and borrowing levels which serve as effective tools in mitigating liquidity risk.

Moreover, the paper provides novel theoretical and practical contributions demonstrating the inconsistency of liquidity risk determinants for banks with different liquidity risk levels. Based on this study's findings, bank managers should consider the significance and the magnitude of each micro- and macro-level variable impact on bank liquidity risk grounded on their prevailing liquidity risk level.

Furthermore, the paper has methodological contribution in the Egyptian market context, as it employs several advanced nonparametric econometric approaches. This is the first study to employ the DEA method in estimating the examined banks' intermediation efficiency scores and the conditional quantile regression in examining the impact of bank intermediation efficiency on liquidity risk under different liquidity risk quantiles. The findings support the study's argument stating the higher significant positive impact of intermediation efficiency on reducing the liquidity risk of banks that are characterized by undertaking high liquidity risk levels.

Policy implications

Efficiency measurement of banks helps to understand the health of the banking system. Particularly, intermediation efficiency has several important implications for

policymakers to improve Egypt's financial sector operational efficiency and financial solidity. Thus, the findings of this research propose valuable policy implications to surge development in the Egyptian financial service sector which is essential for economic prosperity.

Egypt's banking reform programs designed with help of the International Monetary Fund and the World Bank aim at decreasing the government's role in the financial sector while encouraging private sector investments. This paper's findings highlight the positive impact of this transformation on private banks' performance that have recently demonstrated competitive efficiency in managing their intermediation role compared to public banks. Based on this paper's results, policy makers would be encouraged to develop appropriate regulations to encourage private banks to engage in more diverse financial operations, such as lending, trading, and investment, to enhance competition for improving the Egyptian banking sector efficiency.

In addition, Egypt is witnessing continuous financial technology changes in the financial landscape. This paper's results demonstrate that financial technological innovation is a novel mean for banks to increase their financial intermediation efficiency. Thus, given the growth of bank digitalization in the recent decade, policymakers in Egypt should enact policies that assist banks in pursuing financial innovation.

Moreover, the various worldwide financial and economic crises that took place in recent years has elevated doubt that the high levels of banks' encountered risks would negatively affect the solidity of several financial markets. Consequently, this paper conducted analysis of banks' liquidity risk, one of the major bank risks. The paper findings highlight the significance for policymakers to guarantee that banks operate efficiently in terms of employing their financial intermediation role, which can ultimately minimize their liquidity risk levels.

Furthermore, this paper demonstrates banks' liquidity risk determinants according to banks' liquidity risk levels. Based on this paper's results, policy makers would formulate regulatory framework that considers the bank-level and macro-level liquidity risk determinants. Consequently, policy makers in Egypt would proceed with the financial sector reforms while identifying the proper policies to be employed.

Limitations and direction for future studies

One of the limitations of this study is its small sample size due to the low number of public banks operating in Egypt. To overcome this limitation, future papers could expand the sample to cover the MENA region. Thus, this would result in more generalizability of the research findings. Moreover, since this paper employs DEA in its bank

intermediation efficiency measurement, the findings might be sensitive to the inputs and outputs selection. Consequently, future studies could use other inputs and outputs to assess different types of efficiencies, such as cost efficiency or profitability efficiency. These supporting methods would result in producing reliable findings and help in conducting comparative analysis between the examined banks under several efficiency dimensions.

Abbreviations

DEA	Data envelopment analysis
DMUs	Decision-making units
CBE	Central Bank of Egypt
CCR	Charnes–Cooper–Rhodes
VRS	Variable returns to scale
CRS	Constant returns to scale
BCC	Banker, Charnes, and Cooper
LR	Liquidity risk
IE	Intermediation efficiency
LL	Loan loss (asset quality)
ETA	Equity to total assets (capital)
ROA	Return on assets (profitability)
S	Size
LTA	Loans to total assets (asset concentration)
GDP	Gross domestic product
CAPMAS	Central agency for public mobilization and statistics
VIF	Variance inflation factor (VIF)

Acknowledgements

Not applicable.

Author contributions

Not applicable.

Funding

The study did not receive any funding.

Availability of data and materials

Data will be made available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

Not applicable.

Received: 29 May 2024 Accepted: 8 August 2024

Published online: 20 August 2024

References

- Abbas J, Hussain I, Hussain S, Akram S, Shaheen I, Niu B (2019) The impact of knowledge sharing and innovation on sustainable performance in Islamic banks: a mediation analysis through a SEM approach. *Sustainability* 11(15):4049
- Abbas J, Mubeen R, Iorember PT, Raza S, Mamirkulova G (2021) Exploring the impact of COVID-19 on tourism: transformational potential and implications for a sustainable recovery of the travel and leisure industry. *Curr Res Behav Sci* 2:100033
- Abbas J, Zhang Q, Hussain I, Akram S, Afaq A, Shad MA (2020) Sustainable innovation in small medium enterprises: the impact of knowledge management on organizational innovation through a mediation analysis by using SEM approach. *Sustainability* 12(6):2407
- Abdelaziz H, Rim B, Helmi H (2022) The interactional relationships between credit risk, liquidity risk and bank profitability in MENA region. *Glob Bus Rev* 23(3):561–583
- Att-Sahalia Y, Lo AW, (2000) Nonparametric risk management and implied risk aversion. *J Econom* 94(1–2):9–51
- Akhtar S, Alam M, Khan A, Shamshad M (2023) Measuring technical efficiency of banks vis-à-vis demonetization: an empirical analysis of Indian banking sector using CAMELS framework. *Qual Quant* 57(2):1739–1761
- Altunbas Y, Carbo S, Gardener EPM, Molyneux P (2007) Examining the relationships between capital, risk and efficiency in European banking. *Eur Financ Manag* 13(1):49–70
- Amin SIM, Mohamad SHAMSHER, Shah ME (2017) Do cost efficiency affects liquidity risk in banking? Evidence from selected OIC countries. *Jurnal Ekonomi Malaysia* 51(2):55–71
- Bangarwa P, Roy S (2023) Operational performance model for banks: a dynamic data envelopment approach. *Benchmarking Int J* 30(10):3817–3836
- Banker RD, Charnes A, Cooper WW (1984) Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Manag Sci* 30(9):1078–1092
- Beccalli E, Casu B, Girardone C (2006) Efficiency and stock performance in European banking. *J Bus Finance Account* 33:245–262
- Berger AN, Bouwman CHS (2009) Bank liquidity creation. *Rev Financ Stud* 22(9):3779–3837
- Central Bank of Egypt (2023) Egypt FinTech landscape report. <https://fintech-egypt.com/FinTechEgypt2023/>.
- Charnes A, Cooper WW, Rhodes E (1978) Measuring the efficiency of decision making units. *Eur J Oper Res* 2(6):429–444
- Chortareas G, Girardone C, Ventouri A (2011) Bank supervision, regulation, and efficiency: evidence from the European Union. *J Financ Stab* 8(4):292–302
- Chulia H, Koser C, Uribe JM (2021) Analyzing the nonlinear pricing of liquidity risk according to the market state. *Finance Res Lett* 38:101515
- Colbert A, Levary RR, Shaner MC (2000) Determining the relative efficiency of MBA programs using DEA. *Eur J Oper Res* 125(3):656–669
- De Nicolo G (2000) Size, charter value and risk in banking: An international perspective. *International Finance Discussion No 689 Board of Governors of the Federal Reserve System*.
- El-Massah S, Bacheer SM, Sayed OA (2019) Liquidity risk in the MENA region banking sector: does bank type make a difference? *J Dev Areas* 53(1):147–163
- Fouad J, Said M, Sherif W, Zaki C (2022) Public banks and development in Egypt: overview, issues and the way forward. *Economic Research Forum (ERF)*.
- Ghenimi A, Chaibi H, Omri MAB (2021) Liquidity risk determinants: Islamic vs conventional banks. *Int J Law Manag* 63(1):65–95
- Gökgöz F, Yalçın E (2022) A slack-based DEA analysis for the world cup teams. *Team Perform Manag Int J* 28(1/2):1–20
- Gökgöz F, Yalçın E, Salahaldeen NA (2023) Investigating the financial efficiencies and productivities of the banking sector. *J Econ Stud*
- Golany B, Roll Y (1989) An application procedure for DEA. *Omega* 17(3):237–250
- Hassan H, Jreisat A (2016) Does bank efficiency matter? A case of Egypt International. *J Econ Financ Issues* 6(2):473–478
- Horvat AM, Milenković N, Dudić B, Kalaš B, Radovanov B, Mittelman A (2022) Evaluating bank efficiency in the West Balkan countries using data envelopment analysis. *Mathematics* 11(1):15
- Imbierowicz B, Rauch C (2014) The relationship between liquidity risk and credit risk in banks. *J Bank Finance* 40:242–256
- Kim C (2015) Liquidity risk regulation and bank performance. Evidence from European bank. *Glob Econ Finance J* 8(1):11–33
- Koenker R, Hallock KF (2001) Quantile regression. *J Econ Perspect* 15(4):143–156
- Kumar VP, Kar S (2023) Measuring the efficiency of Indian public and private banks using the two-stage network DEA model. *Benchmark Int J* 30(2):382–406

31. Kweh QL, Lu WM, Tone K, Liu HM (2024) Evaluating the resource management and profitability efficiencies of US commercial banks from a dynamic network perspective. *Financ Innov* 10(1):19
32. Li L (2014) The impact of non-interest income on the efficiency of China's banking sector. *J Stock Forex Trad* 3:1–8
33. Milenković N, Radovanov B, Kalaš B, Horvat AM (2022) External two stage DEA analysis of bank efficiency in West Balkan countries. *Sustainability* 14(2):978
34. Mohieldin M, Hussein K, Rostom A (2019) On financial development and economic growth in Egypt. *J Hum Appl Soc Sci* 1(2):70–86
35. Nia NM, Alouj HA, Pireivatlou AS, Ghezelbash A (2012) A comparative profitability efficiency study of private and government banking system in Iran applying data envelopment analysis (DEA). *J Basic Appl Sci Res* 2(11):11603–11614
36. Noulas AG (2001) Deregulation and operating efficiency: the case of the Greek banks. *Manag Finance* 27(8):35–47
37. Pasha R, Elbages B (2022) Green banking practices: The impact of internet banking on bank profitability in Egypt. *Corp Bus Strategy Rev* 3(2):65–75
38. Patra B, Padhan PC, Padhi P (2023) Efficiency of Indian Banks—private versus public sector banks: a two-stage analysis. *Cogent Econ Finance* 11(1):2163081
39. Poshakwale SS, Qian B (2011) Competitiveness and efficiency of the banking sector and economic growth in Egypt. *Afr Dev Rev* 23(1):99–120
40. Ramanathan R (2007) Performance of banks in countries of the Gulf Cooperation Council. *Int J Product Perform Manage* 56(2):137–154
41. Safa M, Ali MH, Ismail A, Amin IM, Ali MH, Nor SM (2018) Cost efficiency and liquidity risk in banking: new evidence from OIC countries International. *J Bus Manage Sci* 8(2):255–276
42. Tan Y (2016) The impacts of risk and competition on bank profitability in China. *J Int Financ Mark Inst Money* 40:85–110
43. Yeh QJ (1996) The application of data envelopment analysis in conjunction with financial ratios for bank performance evaluation. *J Oper Res Soc* 47:980–988
44. Zhu N, Shah WUH, Kamal MA, Yasmeen R (2021) Efficiency and productivity analysis of Pakistan's banking industry: a DEA approach international. *J Financ Econ* 26(4):6362–6374
45. Zolkifli NA, Abdul Hamid M, Hawati Janor H (2015) Liquidity risk and performance: the case of Bahrain and Malaysian banks. *Glob Econ Finance J* 8(2):95–111

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.