Fintech-based financial inclusion and bank risk-taking: Evidence from OIC countries

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A B S T R A C T

Financial inclusion has gone beyond the rhetoric surrounding social development and financial stability, but also expanding into pathos of arbitrage benefits made from cheap retail deposits by large banks and banks from technologically developed regions. This study investigates whether a higher degree of fintech-based financial inclusion (FFI) intensifies banks' risk-taking by analysing data from 534 banks from 24 OIC countries. The results indicate that higher degree of FFI controls bank's risk-taking behaviour. The nexus turns stronger in the post-industrial revolution 4.0 (IR4.0) era. Our results are robust across multiple proxies and estimation methods. We discuss how competition surrounding investing in fintech may expose the banks towards severe uncertainty.

1. Introduction

Financial inclusion assumes that participants in financial intermediation will have full access to all the possible financial instruments and sources of information, leading to reduced cost of financing and asymmetric information, increase in employment and financial stability (Allen et al., 2016; Banerjee et al., 2013; Beck et al., 2011; Ahamed and Mallick, 2019). As the banks have learned the hard way, after the financial crisis of 2007–08, more investment in financial technologies have emerged to diversify financing sources from risky wholesale deposit to cheap and stable retail deposit (Demirgüç-Kunt and Huizinga, 2010). Policymakers, including government, multilateral development agencies, such as the IMF, World Bank, and central bankers, forward procedures to integrate financial technologies to ensure a higher degree of financial inclusivity that helps break racial, religious, ethnic, and geographic barriers to socio-economic development (Klapper et al. (2016)). At the macro level, inclusive financial sector has contributed positively to employment generation, reduced inequality, financial literacy, and consumer protection (Prasad, 2010; Klapper et al. (2006); Karlan et al., 2014). Consequently, financial inclusion, particularly the strategy based on fintech, has become an effective policy tool (Demirguc-Kunt et al., 2015).

Despite several ground-breaking takeaways, fintech-based financial inclusion (FFI) has found serious opponents. At the macro level, FFI requires countries to establish expensive technology infrastructure in order ensure a symmetric level of financial inclusion

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(Barik and Sharma, 2019). Uneven development with respect to the infrastructure favours the 'size' hypothesis where larger banks with sizeable liquidity and lofty investment in technology make the most out of the technology-arbitrage provided by FFI (Bertay et al., 2013). Having said that, countries with higher quality of institutions are expected to invest more into FFI to reach a higher level of financial stability (Ahamed and Mallick, 2019). At the institutional level, banks may find it rewarding to take more risk since financial inclusion has offered them with much cheaper cost of funding (Acharya and Naqvi, 2012). Hence, banks with excess liquidity and large size, unless strongly supervised, will have the tendency to increase risky investment, which may eventually come at the cost of taxpayers money to bail these banks out of crisis.

While literature on financial inclusion and stability is on the rise, the same connecting FFI and banks' risk taking is found to be limited. In particular, the banks from emerging markets, including the Organization of Islamic Conference (OIC) countries, may find achieving FFI relatively more complex than banks from technologically advanced countries. According to OIC-SESRIC (2021), OIC countries form a league of fifty-seven member countries based on 'Islam' being the state religion, and 'Muslim' being the dominant group in the population. Most of the member countries come from Africa, East Asia, and South Asia. These countries are strikingly vital for financial inclusion and stability as they hold 25% of the global population (1.8 billion), with a growing segment of young population that embrace financial technology. Banks in OIC countries promote several forms of Islamic financial services, with a growing investment in FFI. Due to religious restrictions, Islamic banks were found to be resilient to risks as the Shariah guidelines control the risk-taking behaviour of the Islamic banks (Hassan et al., 2019; Abedifar et al., 2013). On the other hand, Islamic banks generally holds more liquidity than their conventional counterparts due to the lack of Shariah compliant short-term investment opportunities (Berger et al., 2019). Finally, FFI is found to be extremely diverse among OIC countries, leading to suspected influence of bank- and country-specific factors.

Theoretically, this study considers the importance of control of asymmetric information to ensure financial stability (Mishkin, 1992). Technology-centric financial development promises inclusive growth, which may control banks' intention to engage into risky ventures (Levine, 2012). This study fulfils the gap in the literature by investigating the influence of FFI on banks' risk-taking in selected OIC countries after controlling for institutional quality, several types of risks in banks, and other bank- and country-specific characteristics. Given the unique appeal of the OIC countries, results of this study contribute to the limited understanding on the 'digital readiness' and the 'risk appetite' of the emerging country banks. We have also investigated these findings into two regimes: pre- and post-industrial revolution eras (IR4.0) that carry policy implications for bankers and regulators.

IR4.0 introduces a new chapter on how we are expected to interact with and value others in the near future. Technology-enhanced tools and processes will occupy a large part of our activities, impacting individuals, families, and societies, with a vision to deliver an inclusive society[1]. Primary takeaway from IR4.0 includes making peoples' lives easier, smarter, cost efficient, inclusive, and sustainable (Schwab (2015)). The unnerving part is that over half of the global workforce will see a major shift in work style. Consequently, millions of new jobs are to be created in Asia and Africa to compensate for the growth of young population in these regions and the loss of jobs due to automation (Choi, 2017). While there are several challenges surrounding acceptance of the new norms by users and massive amount of investment needed to create awareness, benefits are far reaching too. Considering the growth and challenges faced by OIC member countries due to IR4.0, deeper investigations are needed to examine the impact of FFI on stability of the financial system.

This study investigates the FFI and risk-taking of banks from 24 OIC countries. The final sample includes 428 conventional banks, 99 Islamic banks, 4 cooperative banks and 3 savings banks for the period 2011–2019. Due to unavailability of direct measures, we have employed three measures of FFI, Z-score and the three decomposed risk factors (i.e., default risk, leverage risk and portfolio risk), bank specific factors, such as the bank size, loan share, deposit share and so on, and country specific factors, including the GDP growth, inflation and institutional quality. A range of panel OLS, two-stage least squares, and quantile regression techniques were used to test the models. Our foremost contribution is the creation of the three FFI indices for OIC region. The supply of digital financial services – denoted as FACCESS, which comprises of 'mobile money agent' and 'POS terminals'. The demand side of the index is denoted as FUSAGE, which comprises of 'mobile money and e-money accounts', 'frequency of mobile and internet banking transactions', and 'value of mobile and internet banking transactions'. A combined index – FFI – is also created using principal components of FACCESS and FUSAGE variables.

Our results forward that there exists a strong and robust negative connection between FFI and bank risk-taking. The relationship is amplified in the post-IR4.0 introduction (since 2016). Our results suggest that FFI reduces banks' tendency to take unnecessary risk – certainly more effectively in the post-IR4.0 period and in countries with higher quality of institution, which strongly contributes to the financial agility in the selected countries. We explain the importance of degree of competition and bank sector merger as the new domain of fintech-based inclusion, which is expected to push relatively smaller banks in severe uncertainty.

Our study is an extension from Ahamed and Mallick (2019) from several grounds. Firstly, they have employed traditional FFI measures, such as the number of ATMs, bank branches, and bank accounts to measure financial inclusion index. we take variables that are solely related to the digital financial activities, including the mobile and internet-based financial services to measure FFI indices. Secondly, we offer the evidence on the most recent data until 2019 whereas Ahamed and Mallick (2019) have considered until 2012. Thirdly, unique to FFI-stability nexus, we have categorised data based on the introduction of IR4.0. The post-IR4.0 starts from the year 2016, which is expected to support significant and meaningful conversation on fintech, inclusive growth and stability. Finally, we also offer evidence on Islamic banks from OIC countries that can be taken as lessons for high growth Islamic banking fintech sector. Our findings carry far-reaching implications for banks and policymakers, particularly in the post-pandemic and post-IR4.0 era when personal technologies will lead socio-economic development. Banks may find the results appealing if they are looking for motivations to investment in financial technology in countries with diverse demographic background, such as the countries from OIC bloc.

The reminder of the paper goes as follows. In Section 2, we discuss relevant literature. Section 3 provides details on the data, their

sources, and methods used to test the models. In this section, we provide details on each proxy used and constructed for the purpose of the study. Results and their discussions appear in Section 4. Section 5 concludes the study with summary of the findings and their implications for the future studies.

2. Literature review

Only a handful of studies consider the inclusion-stability nexus at the institutional level. Most researchers censure scarcity of long series of FFI data for lack of studies on the stability, inclusion, and banks' overall risk exposure (Danisman and Tarazi, 2020). We approach this connection from a different perspective by coupling the stability of the financial institution from the OIC countries with a segmented look at the pre- and post-IR4.0 eras, fintech-based financial inclusion, and quality of institutions.

In general, there are three major hypotheses explaining inclusion-stability nexus. These are (1) diversification, cost reduction and market power, (2) reduced pro-cyclicality, and (3) absorption of inclusion-induced monetary shock (Ahamed and Mallick, 2019; Danisman and Tarazi, 2020). One of the major assumptions that drive these hypotheses is the strong positive connection between financial inclusion and stability. Countries with higher levels of institutional quality and banks with large market share of deposit have reported broader support for these hypotheses. However, countries with lower level of institutional quality may result in credit quality loss, leading to higher proportion of non-performing loans (Čihák et al., 2016; Sahay et al. (2015); De La Torre et al. (2013)).

On the first assumption, most studies find strong support for the positive connection between financial stability and inclusion. As inclusive finance generally invites a wider group of customers into financial domain, either through conventional methods or by using digital financial technologies, banks will generally secure the benefits of 'numbers' in terms of diversification of deposit and loan portfolios, reduction in customer search cost, and increase in stable deposit (Danisman and Tarazi, 2020). However, these benefits come with costs in countries with lesser quality of institutions and limited investment in infrastructure. Banks in emerging countries – for instance, in most of the OIC countries – will have to invest a sizable amount in building technological interface with customers, which may expose banks into a 'single-point' of technology-centric competition against large local and foreign banks (Khan, 2011; Barik and Sharma, 2019). Despite these drawbacks, financial inclusion forwards an efficient mechanism to connect to customers, which will help banks control asymmetric information (Allen et al., 2014).

Banks and financial institutions have experienced direct benefits of financial inclusion. Aside to an overall increase in 'customer engagement', banks found their savings going up (Allen et al., 2016; Vo et al., 2020), opened new areas on investment on technologies that generated new employment (Prasad, 2010), and invested in new venture creation with diverse information collected on the borrowers using financial technologies (Klapper et al. (2006)). One step forward, the cost of retail financing is found to be lower when compared to the same on the wholesale sources (Demirgüç-Kunt and Huizinga, 2010). Higher degree of inclusion enables banks to participate in deposit and lending exercises with relatively disadvantageous groups of the society, leading to a controlled pro-cyclicality risk for banks (Hannig and Jansen, 2010; Han and Melecky, 2013).

While financial inclusion contributes positively to the growth of stable deposit to the financial system, countries can reduce their reliance on and shock of external debt (Demirguc-Kunt et al., 2017). This generally motivates the banks to find the right mix of their financing that significantly influences banks' strategic risk-taking (Ayadi and De Groen, 2014). As a result, banks will be able to amplify their motivation to risk-taking given the strong liquidity and market power (Smaoui et al., 2020). Previously, this view of risk-taking was criticised as the banks are expected to reduce their risk taking when the cost of funding drops (Petersen and Rajan, 1995). Hence, banks can lend small firms with a much higher assurance of getting the investment back (Morgan and Pontines, 2014). In return, in the long-run, financial inclusion achieves a higher level of financial stability (Mendoza et al., 2009; Dabla-Norris et al. 2015).

Evidence on inclusion and risk-taking behaviour is mixed. In the IR4.0 era, banks are expected to increase the degree of digital inclusion by investing more on technology as it provides an effective interface between the bank and the customers. Using technology as the backdrop, banks expect to reduce the physical distance with the customers to build long-term stable relationship, to help un-informed and less informed customers, and to collect quality information that helps to build a precise risk profile of the customers (Hauswald and Marquez, 2006). Therefore, higher degree of financial inclusion should result in limited risk-taking (Di Patti and Dell'Ariccia, 2004).

With the amplified adoption of the digital technologies, banks may also find it competitive to retain their market share as other banks will follow similar approaches. This supports the 'size, inclusion and risk-taking' dilemma. Large banks are generally risk averse as they do not face liquidity shortage similar to the smaller banks; these banks can also invest heavily in fintech in order to take the advantage of cheap retail deposit (Bertay et al. 2013). Therefore, relatively smaller banks may have limited takeaways from the 'number' game of financial inclusion. There is general evidence on type of banks – Islamic versus conventional – having strong implications for risk-taking. However, these findings suffer from inconsistency in the presence of various types of risks (i.e., credit, market, and liquidity risks), uniqueness of their operation (shariah compliance), and their approaches to mitigate crisis and handle customer engagement (Smaoui et al. (2020); Rashid et al., 2017).

While studies on OIC countries and IR4.0 have been limited, there are growing literature on fintech-inclusion-stability nexus covering a wide range of contexts. Danisman and Tarazi (2020) investigate 4168 banks from 28 EU countries for the period 2010–2017. They report strong influence of inclusion on bank sector stability. Vo et al. (2020) employ data from 3071 Asian banks for the 2008–2017 period. They have reported that higher degree of financial inclusion connects strongly positively to bank sector stability in Asia. Neaime and Gaysset (2018) take sample from five Middle East and North African countries, such as Tunisia, Libya, Syria, Yemen, and Egypt. Despite diverse demographics and degree of technology adoption, the study has reported strong positive connection between inclusion and banking stability. Ahamed and Mallick (2019) take international sample from 86 countries and forwards a strong inclusion-stability nexus. Banna, Mia, Nourani and Yarovaya (2021) investigate inclusion and risk-taking activities among

microfinance institutions from Sub-Saharan African countries. They agree to the widely held view that inclusion reduces risk-taking in financial institutions.

On the backdrop of these inconsistencies and limited findings, this study aims to investigate the impact of FFI on banks' risk-taking in selected OIC countries. We take data on different types of bank risks and several proxies for FFI that are controlled for bank- and country-specific variables, including institutional quality and bank size, and tested for robustness during pre- and post-IR4.0.

We have arrived at two hypotheses based on above discussions. These are stated below:

H1: Higher degree of fintech-based financial inclusion (FFI) helps reduce banks' risk-taking.
H2: Due to intensity and engagement with technology, FFI-based risk control is more significant at the post-IR4.0 period.

3. Data and methodology

3.1. Data and data sources

We limit our analysis to banking sector only. We choose this sector because overall sustainable economic growth relies on the stability of the financial sector, in particular the banking sector (Banna, 2020). Banking sector is also the most vulnerable sector. In the post global financial crisis period and as the COVID-19 is pushing a global economic meltdown, policymakers are particularly concerned about stabilizing the banking sector. Banks have also increased investment in digital finance to reduce the 'distance' with the customers (Banna et al., 2020).

Due to unavailability of long-series data on FFI, we have chosen 24 OIC countries for data collection. Refer to Table 1 for the list of countries. We have applied filtering process of to have minimum three years of data for a bank to be prelisted in this study. The final sample consisted of 534 banks, which included 428 conventional banks, 99 Islamic banks, 4 cooperative banks, and 3 savings banks,

Table 1
Descriptive Statistics.

Variable definition	Obs.	Mean	Std. Dev.	Min	Max	Source
Panel A: Bank risk-taking						
Default Risk (DRISK): −1* [logarithm {Equity over Assets (EQT) plus Return on Average Assets (ROAA)) / (standard deviation of ROAA)}]	3051	−3.772	1.197	−5.977	−1.385	OBF
Leverage Risk (LRISK): −1* (EQT divided by standard deviation of ROAA)	3070	−3.67	1.188	−5.902	−1.377	OBF
Portfolio Risk (PRISK): −1* (ROAA divided by standard deviation of ROAA)	2760	−1.401	1.314	−3.609	1.42	OBF
Panel B: Bank-specific factors						
Logarithm of Total Assets - Bank Size (SIZE)	3656	6.891	1.677	3.962	9.998	OBF
Total Loans over Total Assets -LOANSHARE (LS)	3598	0.556	0.169	0.18	0.785	OBF
Total Deposits over Total Assets - DEPOSITSHARE (DS)	3595	0.76	0.152	0.316	0.911	OBF
Annual Growth of Total Assets - GROWTH (GTA)	3107	0.092	0.163	-0.186	0.464	OBF
Total Earning Assets over Total Assets -Management Quality (MQ)	3624	0.796	0.14	0.413	0.958	OBF
Panel C: Macro-specific factors						
GDP growth (annual %) (GDPG)	3656	4.83	1.762	0.989	7.864	WDI
Inflation, consumer prices (annual %) (INF)	3634	4.668	3.858	0.135	15.675	WDI
Institutional quality (IQ)	3656	0	0.881	−1.892	1.829	WGI
Panel D: Fintech-based financial inclusion related variables						
Mobile money agent, non-branch commercial bank agent outlets per 1,000 km^2 (AGTOUTKM)	3656	545.185	1417.507	0.436	5503.204	FAS
Mobile money agent, non-branch commercial bank agent outlets and POS terminals per 100,000 adults (AGTOUTAD)	3656	440.185	381.563	2.261	1306.827	FAS & Findex
Number of mobile money and e-money accounts per 1,000 adults (ACTAD)	3656	265.136	301.153	3.079	1049.388	FAS & Findex
Number of mobile and internet banking transaction (during reference year) per 1,000 adults (MITNTRANAD)	3656	22651.94	39233.64	0.131	153,000	FAS
Value of mobile and internet banking transaction (during reference year) (% of GDP) (MIVTRANSAD)	3656	72.233	116.732	0.004	409.05	FAS
Fintech based Financial Inclusion (FFI) – Overall Index using PCA	3656	0.17	0.257	0	1	Authors'
Fintech based Financial Inclusion (FACCESS) – Supply side index PCA	3656	0.136	0.247	0	1	Authors'
Fintech based Financial Inclusion (FUSAGE) – Demand side index using PCA	3656	0.15	0.257	0	1	Authors'
Made or received digital payments in the past year (% age 15 +) (DP)	3334	28.599	19.156	3.555	70.42	Findex
Panel E: Instrumental variables						
Main source of emergency funds: family or friends (% able to raise funds, age 15 +) (FNF)	3334	40.448	15.057	22.315	73.075	Findex
Proportion of other countries in the same region that have mobile phone (per 100 people) (MBSHARE)	3656	0.062	0.032	0.015	0.114	WDI

Note: This table provides the definition and the descriptive statistics (number of observations, mean, standard deviation, minimum and maximum value) of the variables used in this study. Standard deviation of ROAA has been calculated using three (3) years rolling window. IQ index is standardized using six (6) components of good governance namely, control of corruption, government effectiveness, political stability and absence of violence/terrorism, regulatory quality, rule of law, and voice and accountability. PCA refers to principal component analysis. Source: International Monetary Fund Financial Access Survey (FAS), World Bank Global Findex (Findex), Orbis Bank Focus (OBF), World Development Indicators (WDI), and World Governance Indicators (WGI).

with an unbalanced panel data over the 2011–2019 period. The banks were located in six regions: The East Asia and Pacific (EAP), Europe and Central Asia (ECA), Latin America and the Caribbean (LAC), Middle East and North Africa (MENA), South Asia (SA), and Sub-Saharan Africa (SSA). Our study considers this timeframe because the FFI data[2] is available from 2011 onward. Besides, the Bureau van Dijk Orbis Bank-Focus database provides the current bank-specific data from 2011 to 2019. We took the year 2016 and onward as the IR4.0 era. IR4.0 was first coined by Klaus Schwab in December 2015 through an article on Foreign Affairs, which later became the theme of the World Economic Forum Annual Meeting in 2016 (Schwab (2015)). In line with this, we divided our sample into two regimes: pre- (2011–2015) and post-IR4.0 (2016–2019) introduction era. Appendix A1 presents that Indonesia (21.35%), Bangladesh (10.49%) and Malaysia (9%) contributed to the top three largest sample banks for the study.

Our data came from several sources: i) Bureau van Dijk Orbis Bank-Focus (Bank Focus) database for bank-specific data; ii) International Monetary Fund for the Financial Access Survey (IMF-FAS), the World Bank Global Findex (Findex) database for the FFI data; and iii) the World Development Indicators (WDI) and the World Governance Indicators (WGI) databases for the macroeconomic factors; and iv) previous literature for instrumental variables' data. We winsorised each variable at the 5th and 95th percentile to reduce the effect of outlier.

3.2. Methodology

3.2.1. Bank risk-taking

Following the studies by Danisman and Tarazi (2020) and Khan et al. (2017), we considered three proxies for bank risk-taking: a) Default risk, b) Leverage risk, and c) Portfolio risk. These three are the dependent variables of the study. We took *z*-score for the default risk, which appeared widely in relevant studies (Danisman and Tarazi, 2020; Houston et al., 2010; Laeven and Levine (2009)). We denoted risk-taking as the opposite of bank stability: higher (lower) degree of the risk-taking indicates lower (higher) bank stability. Equation (1) provides the formula for *z*-score.

$$Z - score_{it} = \frac{ROAA_{it} + EQT_{it}}{\sigma(ROAA)_{it}} \tag{1}$$

Here, $ROAA_{it}$, EQT_{it} and $\sigma(ROAA)_{it}$ are the return on average assets, the equity to asset ratio, and the standard deviation (σ) of ROAA of bank '*i*' in year '*t*' respectively. To calculate the $\sigma(ROAA)$, we considered 3-year rolling period to allow for the variation in the *z*-score. As the *z*-score is found to be highly skewed, natural logarithm was used to reduce the skewness. To make the analysis simple, we multiplied '-1′ with log of *z*-score to create DRISK (default risk). With the new variable, a higher *z*-value suggested higher (lower) risk-taking (bank stability). We also decomposed the *z*-score to get the leverage risk and portfolio risk. Alongside using log transformation, leverage risk (LRISK) and portfolio risk (PRISK) were proxied by (-1* (EQT/$\sigma(ROAA)$)) and (-1* (ROAA/$\sigma(ROAA)$)) respectively.

3.2.2. Fintech-based financial inclusion index (FFI)

Due to unavailability direct proxies, we considered variables that were solely related to the digital financial activities (mobile and internet-based financial services) to create FFI indices. Following the suggestions from relevant previous studies (Ahamed and Mallick, 2019; Banna and Alam, 2020; Banna et al. 2020), we created access to digital finance (supply side) as well as the usage of digital finance (demand side) FFI proxies for OIC region. While previous studies employed the number of ATMs, bank branches, and bank accounts as financial inclusion proxies, this study considered the number of mobile money agent and non-branch commercial bank agent outlets, point of sales (POS) terminals, mobile money accounts, and mobile and internet banking transactions to construct a comprehensive FFI index. See Siddik and Kabiraj (2020) for discussion on similar proxies. Appendix A2 shows the variables used for constructing the FFI index.

As the variables in the FFI index may raise multi-collinearity and over-parameterisation issues (Ahamed and Mallick, 2019), this study develops an inclusive index of FFI to capture the most common variation among the proxies using principal components analysis (PCA[3]). We normalised the value of each indicator between '0′ to '1′. Using PCA, we created a supply side index using two indicators (AGTOUTKM and AGTOUTAD). We denoted this as FACCESS. Likewise, we created an index for the demand side using MITNTRANAD, MIVTRANSAD and ACTAD. We noted it as FUSAGE. Finally, we combined these two indices (FACCESS and FUSAGE) to construct the FFI index. All these three indices have been normalised using minimum–maximum normalisation technique.

3.2.3. Bank and macro-economic variables

The study controlled for several bank- as well as country-specific factors. This study used logarithm of total assets (Bank size – SIZE) to capture the 'size' hypothesis. Ratio of total loans over total assets (Loan share - LS) was considered to account for the liquidity risk. Deposit share was calculated using the ratio of total deposits over total assets (Deposit share – DS). Better management quality can reduce excessive risk-taking tendency. The ratio of total earning assets to total assets (Management quality - MQ) was taken to proxy MQ. We also controlled for the annual growth of total assets (Asset growth – GTA).

To address country-specific variation, we considered annual GDP growth (GDPG) and Inflation rate (INF). To control for the institutional quality (IQ), we used the standardised approach of the governance indicators stated in Kaufmann et al. (2010). The WGI consisted of six components[4], namely Control of Corruption, Government Effectiveness, Political Stability and Absence of Violence/Terrorism, Regulatory Quality, Rule of Law, and Voice and Accountability.

3.3. Estimation technique

To investigate the impact of the FFI on bank risk-taking, the following baseline regression analysis has been used in this study.

$$Y_{ijt} = \alpha + \beta FFI_{jt} + \varnothing X_{ijt} + \omega Z_{jt} + \varepsilon_{ijt} \quad (2)$$

where, Y_{ijt} = *DRISK, LRISK and PRISK* are the proxies for the bank risk-taking for bank '*i*' of country '*j*' in year '*t*'. FFI_{jt} = three FFI indices of country '*j*' in year '*t*'. X_{ijt} = Bank-specific factors of bank '*i*' of country '*j*' in year '*t*'. Z_{jt} = country-specific factors of country '*j*' in year '*t*'. β, $\varnothing$, ω represent the coefficients of the variables and ε_{ijt} measures the error term.

After controlling for the heteroscedastic-corrected robust standard error, we employed the pooled ordinary least square (OLS) method examine the fundamental relationship. This study used panel-corrected standard errors (PCSE) method suggested by Beck and Katz (1995) and Alfadli and Rjoub (2019) to observe the robustness of the FFI-bank risk-taking nexus. The PCSE takes care of the sequential correlation and cross-sectional dependence. To minimise the potential endogeneity issues in the form of reverse causality, following Ahamed and Mallick (2019) and Kim et al. (2020), this study employed a Two-Stage Least Squares - Instrumental Variable (2SLS-IV) method. In addition, bank and time fixed effects taken into consideration. We used Quantile Regression (QR) estimation technique to examine the impact of FFI on conditional distribution of bank risk-taking. Several measures are considered to address bank-level competition in selected countries. We reported the results for the full period as well as the two regimes of the IR4.0.

4. Results

4.1. Descriptive statistics

Table 1 shows the descriptive statistics. On the average, the sample banks have a DRISK value of −3.8 with 1.20 SD, a LRISK value of −3.7 with 1.18 SD, and a PRISK value of −1.4 with 1.3 SD. Similar to Abedifar et al. (2013), Fig. 1 indicates that the Islamic banks are less risk-taking than the conventional banks. However, the volatility of the risk-taking is generally time-varying. OIC countries have reported 4.8% GDP growth and 4.7% inflation rate over the sample years from 2011 to 2019. COVID-19 is expected to carry a long-term impact on banks' risk-taking and financial stability globally.

4.2. Fintech-based financial inclusion

On an average, there are 545 and 440 mobile money and non-branch commercial bank agent outlets per 1000 km^2 and mobile money, non-branch commercial bank agent outlets and POS terminals per 100 k adults respectively in OIC countries. Furthermore, the number of mobile money and e-money accounts is 265 per 100 k adults. The number and the value of mobile money and internet banking transactions per 1000 adults are approximately 22,651 and 72 respectively. These indicate that the existing bank and mobile

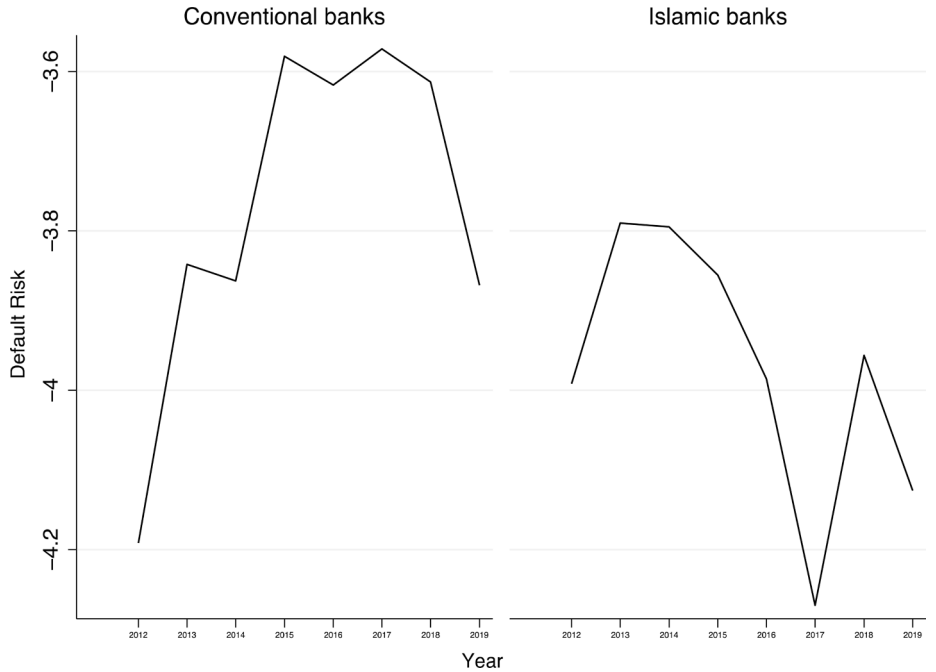

Fig. 1. Default risk of conventional banks and Islamic banks over the year 2012–2019. Source: Author's calculation using Orbis bank focus data.

money account holders are well snug of using mobile banking facilities.

Fig. 2 demonstrates that Malaysia holds a better score for FFI index and FUSAGE index, followed by Uganda, while Bangladesh is in a better position in terms of FACCESS index. Iraq and Chad have the lowest scores in FFI and FUSAGE indices and Qatar has the lowest score in FACCESS index.

Fig. 3 reports that expect for EAP, OIC countries in remaining regions score low on the FFI index. Among them, countries in MENA have reported the lowest score in all indices, followed by the countries in LAC. Countries in EAP hold the highest score in FFI, followed by the South Asian countries. Comparing the two extreme time points from the sample – 2011 and 2019, we can safely conclude that countries the EAP, SA and SSA regions have progressed remarkedly on FFI scores. The diversity of scores also indicates the possibility of further enhancement of digital inclusion.

4.3. Fintech-based financial inclusion (FFI) and bank risk-taking

This subsection provides the main results. Variance inflation factor from the Appendix A3 reports that none of the independent variables violate the multicollinearity issue. Results are shown in Table 2. We control for the bank-, country-specific variables, alongside year and bank fixed effects. We have divided our analysis based on two dimensions: a) three proxies of bank risk-taking: Default risk (DRISK) (Model 1–3), Leverage risk (LRISK) (Model 4–6), and Portfolio Risk (PRISK) (Model 7–9); b) three indices of FFI (Model 1,4 and 7), Access to digital finance (FACCESS) (Model 2, 5 and 8), and Usage of digital finance (FUSAGE) (Model 3, 6 and 9).

Results in Table 2 suggest that for the full sample over the year 2011 to 2019, at 1% level, FFI reduces banks' risk-taking for all three risks. The coefficients of FFI indices on the bank risk-taking suggest that an increase in one standard deviation of the FFI index (SD 0.17) is associated with a decline in the default risk and leverage risk by 12.92% (0.17 × -0.76) and a decline in the portfolio risk by 7.99% (0.17 × -0.47). The coefficients are significant and negative also for 'access to FFI' index for the cases of default risk and liquidity risk, but insignificant for portfolio risk. For 'usage of FFI' index reports strong negative connection to all three risks, indicating strong downfall of risk-taking due to fintech based financial inclusion by banks. Our results demonstrate strong support for the lion share of the extant studies exhibiting a negative relationship with bank risk-taking (Ahamed and Mallick, 2019), which in turn translates into a positive connection with financial stability.

In Table 3, we have split our sample into two sub-samples to investigate the potential impact of IR4.0 on the FFI - bank risk-taking nexus. Panel A shows the results for the pre-IR4.0 (year 2011 to 2015), whereas Panel B displays the results for post-IR4.0 era (year 2016 to 2019). Structures of the models based on type of risks are same as those in Table 2.

In Panel A, FFI and bank risk-taking nexus exhibits a weaker connection during the pre-IR4.0. However, the same in Panel B has improved significantly with the post-IR4.0. At the early stage of digitalization, FFI-bank risk-taking is not much effective. With the passage of time, and after announcement of IR4.0 era, the nexus has become stronger. The transformation towards institutional IR4.0 involves a large amount of capital, high operational costs, communication costs and coordination cost to establish fintech-based

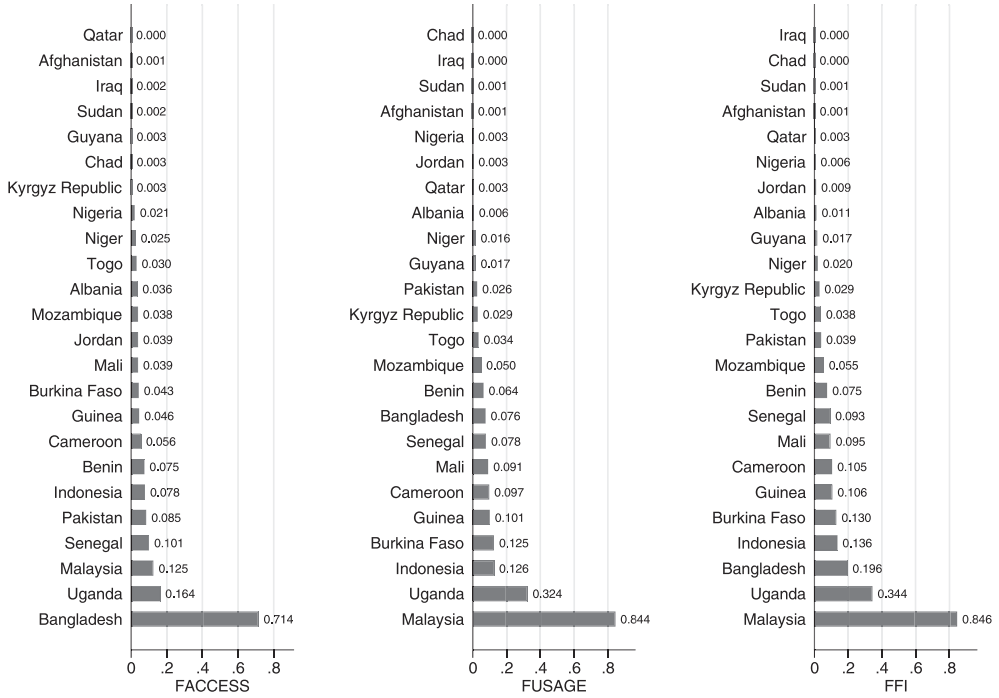

Fig. 2. Fintech-based financial inclusion indices among countries. Source: Author's calculation based on FAS and Findex data.

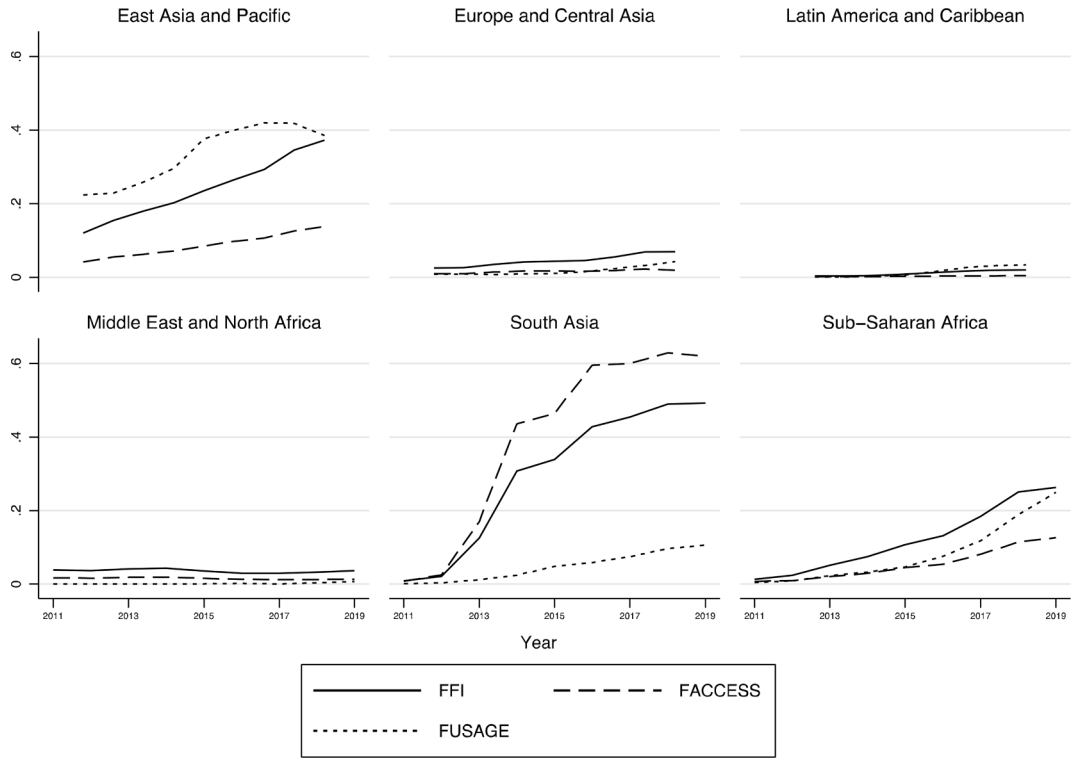

Fig. 3. The mean score of overall FFI, FACCESS and FUSAGE indices (by region and year). Source: Author's calculation based on FAS and Findex data.

financial system. The additional investment places a greater financial pressure on banks, thus increases their risk level in the short run (Wang et al., 2020). Besides, it takes a 'long drive to reach maturity' level to cope-up with the existing technological development patterns (Rostow, 1959). Remarkably, the FFI - bank risk-taking nexus takes relatively lesser time to reach a strong relationship, which is a direct result of policy-level implementation of IR4.0 through change in banking model, use of agent banking, and investment in internet banking.

The results also advise that FFI carries both economic and policy importance, which includes a controlled banks' risk appetite, arresting crisis spilling over to cross-pillar of financial services, and increasing the scope of financial mobility in the region. Thanks to the FFI, with the cheap financing cost, banks will help mobilize financial resources much faster, resolving banks' liquidity crisis. This is of particular importance to Islamic banks that are suffering from liquidity shortage due to restricted use of conventional instruments. FFI also helps the banks to reduce the pro-cyclicality risk by targeting a good mix of qualified and well deserved but financially disadvantageous groups, say SMEs (Han and Melecky, 2013). Thus, in the post-IR4.0 era, with an inclusive fintech-based financial sector, banks are likely to enjoy lower (greater) risk-taking (financial stability).

4.4. Robustness test

4.4.1. Robustness: Panel-corrected standard errors (PCSE)

We choose PCSE to reduce the prevailing issues of sequential correlation and cross-sectional dependency and capture the likelihood of endogeneity using a suitable instrument (Alfadli and Rjoub, 2019). We tested three models each for three inclusion indices and three periods: full, pre-IR4.0 and post-IR4.0. We take DRISK[5] as bank risk-taking proxy. The findings in Appendix A4, overall, remain unchanged, indicating the robustness of the OLS results. The FFI - bank risk-taking nexus is significant in the post-IR4.0 and insignificant in pre-IR4.0 in all indices of the FFI.

4.4.2. Robustness: Two-Stage least squares - instrumental variables model

Despite using a mixture of country- and bank-level variables that may help to reduce endogeneity problem, we test further on endogeneity issue using 2SLS-IV[6] following Kim et al. (2020). In search of suitable instrumental variables (IVs)[7] relevant to our study, following Ahamed and Mallick (2019), Banna et al. (2021), and Banna (2020), this study considers 'proportion of Mobile cellular subscriptions (per 100 people) - (MBSHARE)' in other countries in the same region as an instrumental variable for 2SLS-IV technique. We have categorised countries based on High-Income, SS, ECA, SSA, EAP, and the MENA regions. It is argued that the banking operational costs as well as physical and financial infrastructural deficiencies can be reduced through good communication infrastructure (Beck et al. 2007) and excessive use of mobile phone (Allen et al., 2014). Hence, countries with large share of mobile

Table 2
Full sample over the year 2011–2019 – OLS.

	DRISK			LRISK			PRISK		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	FFI	FACCESS	FUSAGE	FFI	FACCESS	FUSAGE	FFI	FACCESS	FUSAGE
FFI	−0.764***	−0.667***	−0.732***	−0.763***	−0.670***	−0.730***	−0.473***	−0.238	−0.469***
	(0.098)	(0.141)	(0.098)	(0.096)	(0.139)	(0.096)	(0.114)	(0.170)	(0.114)
SIZE	−0.103***	−0.119***	−0.105***	−0.087***	−0.102***	−0.088***	−0.187***	−0.198***	−0.187***
	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.020)	(0.020)	(0.020)
LS	−0.530***	−0.335*	−0.548***	−0.436***	−0.242	−0.454***	−0.897***	−0.801***	−0.913***
	(0.171)	(0.175)	(0.171)	(0.168)	(0.172)	(0.168)	(0.196)	(0.202)	(0.196)
DS	0.812***	0.843***	0.841***	0.876***	0.908***	0.904***	−0.044	0.007	−0.030
	(0.178)	(0.183)	(0.178)	(0.175)	(0.180)	(0.175)	(0.198)	(0.201)	(0.198)
GTA	−0.332**	−0.289**	−0.329**	−0.307**	−0.263*	−0.305**	−0.411**	−0.376**	−0.410**
	(0.140)	(0.140)	(0.140)	(0.137)	(0.137)	(0.137)	(0.169)	(0.168)	(0.169)
MQ	−0.899***	−0.666***	−0.891***	−0.949***	−0.717***	−0.941***	−0.927***	−0.770***	−0.925***
	(0.234)	(0.230)	(0.235)	(0.231)	(0.227)	(0.232)	(0.283)	(0.278)	(0.283)
GDPG	0.004	0.028*	−0.003	0.006	0.030*	−0.001	−0.024	−0.018	−0.028
	(0.015)	(0.016)	(0.015)	(0.015)	(0.016)	(0.015)	(0.018)	(0.020)	(0.018)
INF	−0.004	0.011	−0.006	0.001	0.015**	−0.001	−0.020**	−0.014	−0.022**
	(0.007)	(0.008)	(0.007)	(0.007)	(0.007)	(0.007)	(0.009)	(0.009)	(0.009)
IQ	0.114**	0.037	0.100**	0.108**	0.032	0.094*	0.067	0.002	0.061
	(0.050)	(0.048)	(0.049)	(0.049)	(0.047)	(0.048)	(0.059)	(0.057)	(0.058)
Obs.	2965	2965	2965	2984	2984	2984	2683	2683	2683
R-squared	0.198	0.190	0.197	0.207	0.199	0.206	0.145	0.141	0.145
F	42.141***	37.726***	41.818***	44.461***	40.140***	44.095***	25.036***	23.491***	25.061***
Time fixed effect	yes	yes	yes	yes	yes	yes	yes	yes	yes
Bank fixed effect	yes	yes	yes	yes	yes	yes	yes	yes	yes

Note: This table shows the estimation results of the FFI-bank risk-taking nexus controlling the bank-specific and macroeconomic variables deploying the ordinary least square (OLS) estimation technique using full sample period. DRISK, LRISK, PRISK, FFI, FACCESS, FUSAGE, SIZE, LS, DS, GTA, MQ, GDPG, INF, and IQ refer to default risk, leverage risk, portfolio risk, fintech-based financial inclusion index (overall), fintech-based financial inclusion index (access), fintech-based financial inclusion index (usage), bank size, loan share, deposit share, growth in total assets, management quality, GDP growth, inflation, and institutional quality respectively. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively and heteroskedastic corrected standard errors are in parenthesis. Sources: Orbis Bank Focus, WDI, WGI, FAS, Findex.

subscriptions help to facilitate the unbanked people, which may not directly affect the bank risk-taking behaviour but may influence FFI.

In addition to that, we consider 'percentage of adults borrowing from friends and family during emergency funding - (FNF)' as an instrumental variable. Friends and families are the primary source of funding emerging countries (Demirguc-Kunt and Klapper, 2012). It is also evident that only 9% of the adults have borrowed from formal financial sectors, while 29% of the adults have borrowed from friends and family. The higher percentage of adults borrowing from friends and family may influence FFI but not directly affects the bank risk-taking tendency (Ahamed and Mallick, 2019). Similar to the PCSE-based robustness test, we split our sample into two IR4.0 regimes and three FFI indices. We take DRISK as bank risk-taking proxy.

The results in Appendix A5 show outcomes similar to the OLS and PCSE models. The higher value of coefficient shows improved strength of FFI-bank risk-taking nexus, indicating the robustness of the previous findings. Differences between the IR4.0 regimes are also confirmed.

4.4.3. Robustness: Quantile regression (QR) model

The previous estimations using OLS, PCSE and 2SLS-IV restrict the nexus of FFI - bank risk-taking on the basic of the central tendency of probability distributions, which may result in the partial view of the relationship. Moreover, though with a lesser probability, our sample may exhibit heterogeneity non-random selection of banks from selective regions. Hence, following Koenker and Bassett (1978), we investigate whether FFI index has homogeneous effect at different points in the conditional distribution of bank risk-taking. We also split the sample for three time periods: full sample, pre-, and post-IR4.0 era.

The QR estimation results in Appendix A6 suggest that as bank risk-taking (DRISK) changes across quantile, the FFI index varies widely in sign, magnitude, and significance. For the full sample, at 10th quantile the FFI- bank risk-taking is negative but insignificant, however, from the 20th quantile, and above, they become significant with higher magnitude. For pre-IR4.0 era, at 10th and 20th quantile, the nexus is positive and insignificant, and they turn negative and significant at above 60th quantile. For the post-IR4.0 era, the magnitude and significance level increase with the quantiles. Overall, QR estimation results do not offer any surprising results.

4.4.4. Robustness: Alternative proxy for bank risk-taking and FFI

We further consider non-performing loans ratio (NPL) and 'the percentage of adults made or received digital payments in the past year (DP)' as two alternative proxies. The findings in Panel A and B of Appendix A7 confirm our previous results that FFI – bank risk-taking nexus matures with the time, which is generally stronger at the post-IR4.0 era.

Table 3
Sub-sample: Pre-IR 4.0 and Post-IR 4.0 – OLS.

	DRISK			LRISK			PRISK		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	FFI	FACCESS	FUSAGE	FFI	FACCESS	FUSAGE	FFI	FACCESS	FUSAGE
Panel A: Pre-IR 4.0									
FFI	−0.293	−0.333	−0.268	−0.320*	−0.381*	−0.291	−0.048	−0.026	−0.048
	(0.179)	(0.228)	(0.182)	(0.177)	(0.225)	(0.180)	(0.224)	(0.271)	(0.228)
SIZE	−0.036	−0.042*	−0.037	−0.015	−0.022	−0.016	−0.129***	−0.130***	−0.129***
	(0.024)	(0.024)	(0.024)	(0.024)	(0.023)	(0.024)	(0.031)	(0.031)	(0.031)
LS	0.225	0.312	0.225	0.282	0.379	0.283	−0.179	−0.167	−0.180
	(0.268)	(0.269)	(0.269)	(0.264)	(0.265)	(0.264)	(0.321)	(0.323)	(0.322)
DS	0.818***	0.837***	0.832***	0.814***	0.831***	0.829***	−0.138	−0.130	−0.136
	(0.280)	(0.283)	(0.280)	(0.279)	(0.281)	(0.278)	(0.319)	(0.321)	(0.319)
GTA	−0.298	−0.269	−0.294	−0.239	−0.209	−0.234	−0.171	−0.165	−0.171
	(0.207)	(0.203)	(0.207)	(0.205)	(0.201)	(0.205)	(0.261)	(0.256)	(0.261)
MQ	−1.447***	−1.374***	−1.437***	−1.555***	−1.476***	−1.543***	−2.244***	−2.228***	−2.243***
	(0.357)	(0.350)	(0.356)	(0.355)	(0.348)	(0.355)	(0.443)	(0.430)	(0.442)
GDPG	−0.018	−0.011	−0.019	−0.012	−0.005	−0.013	−0.050*	−0.049	−0.050*
	(0.025)	(0.026)	(0.025)	(0.025)	(0.026)	(0.025)	(0.030)	(0.030)	(0.030)
INF	−0.017	−0.011	−0.018	−0.013	−0.007	−0.014	−0.016	−0.016	−0.017
	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.014)	(0.015)	(0.014)
IQ	−0.050	−0.064	−0.058	−0.042	−0.055	−0.051	0.140	0.134	0.139
	(0.076)	(0.073)	(0.075)	(0.075)	(0.073)	(0.074)	(0.090)	(0.088)	(0.089)
Obs.	1261	1261	1261	1269	1269	1269	1166	1166	1166
R-squared	0.161	0.161	0.161	0.173	0.173	0.173	0.123	0.123	0.123
F	19.798***	19.685***	19.758***	21.090***	20.986***	21.044***	14.443***	14.432***	14.441***
Time fixed effect	no	no	no	no	no	no	no	no	no
Bank fixed effect	yes	yes	yes	yes	yes	yes	yes	yes	yes
Panel B: Post-IR 4.0									
FFI	−0.895***	−0.547***	−0.889***	−0.884***	−0.551***	−0.876***	−0.482***	0.236	−0.516***
	(0.118)	(0.189)	(0.118)	(0.115)	(0.185)	(0.116)	(0.134)	(0.230)	(0.134)
SIZE	−0.159***	−0.183***	−0.160***	−0.146***	−0.170***	−0.148***	−0.242***	−0.260***	−0.241***
	(0.022)	(0.021)	(0.022)	(0.021)	(0.021)	(0.021)	(0.027)	(0.026)	(0.027)
LS	−0.840***	−0.697***	−0.873***	−0.740***	−0.596***	−0.771***	−1.305***	−1.349***	−1.328***
	(0.225)	(0.234)	(0.225)	(0.220)	(0.229)	(0.220)	(0.252)	(0.261)	(0.252)
DS	0.812***	0.895***	0.847***	0.925***	1.008***	0.960***	0.044	0.205	0.053
	(0.234)	(0.245)	(0.233)	(0.230)	(0.240)	(0.229)	(0.257)	(0.264)	(0.256)
GTA	−0.560***	−0.499***	−0.568***	−0.550***	−0.487***	−0.558***	−0.736***	−0.726***	−0.743***
	(0.186)	(0.188)	(0.186)	(0.180)	(0.183)	(0.181)	(0.222)	(0.223)	(0.222)
MQ	−0.418	−0.105	−0.424	−0.424	−0.116	−0.429	0.214	0.397	0.199
	(0.315)	(0.309)	(0.316)	(0.309)	(0.303)	(0.310)	(0.369)	(0.364)	(0.369)
GDPG	0.006	0.023	−0.003	0.005	0.022	−0.004	−0.007	−0.027	−0.011
	(0.020)	(0.021)	(0.020)	(0.019)	(0.021)	(0.019)	(0.025)	(0.027)	(0.025)
INF	−0.005	0.011	−0.008	−0.000	0.016	−0.002	−0.020*	−0.019	−0.022*
	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.012)	(0.012)	(0.012)
IQ	0.181***	0.057	0.170**	0.164**	0.044	0.153**	−0.033	−0.152*	−0.032
	(0.069)	(0.066)	(0.068)	(0.067)	(0.064)	(0.066)	(0.081)	(0.078)	(0.080)
Obs.	1704	1704	1704	1715	1715	1715	1517	1517	1517
R-squared	0.228	0.208	0.227	0.238	0.219	0.237	0.158	0.152	0.159
F	42.886***	34.427***	42.866***	45.183***	36.867***	45.083***	23.604***	20.731***	24.011***
Time fixed effect	no	no	no	no	no	no	no	no	no
Bank fixed effect	yes	yes	yes	yes	yes	yes	yes	yes	yes

Note: This table illustrates the estimation results of the FFI-bank risk-taking nexus controlling the bank-specific and macroeconomic variables deploying the ordinary least square (OLS) estimation technique using the sample of pre-IR4.0 period (Panel A) and post-IR 4.0 (Panel B). DRISK, LRISK, PRISK, FFI, FACCESS, FUSAGE, SIZE, LS, DS, GTA, MQ, GDPG, INF, and IQ refer to default risk, leverage risk, portfolio risk, fintech-based financial inclusion index (overall), fintech-based financial inclusion index (access), fintech-based financial inclusion index (usage), bank size, loan share, deposit share, growth in total assets, management quality, GDP growth, inflation, and institutional quality respectively. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively and heteroskedastic corrected standard errors are in parenthesis. Sources: Orbis Bank Focus, WDI, WGI, FAS, Findex.

4.4.5. Robustness: FFI and IR4.0 interaction and their impact on bank risk-taking

In addition, we consider the interaction effect of FFI and IR4.0 to examine the relationship with the bank risk-taking. We code IR4.0 as '1′ for the post-IR4.0 (2016–2019) and '0′ for the pre-IR4.0 (2011 to 2015). Four proxies for the FFI are taken into consideration (FFI, FACCCES, FUSAGE and DP) to find the relationship on bank risk-taking using default risk (DRISK).

The results in Appendix A8 suggest that FFI has significant negative impact on bank risk-taking in all indices except FACCESS. For the interaction effect, the IR4.0 strengthens the FFI- bank risk-taking nexus. This advises that inclusive fintech-based financial system is likely to minimize the bank risk-taking among OIC countries.

4.5. Additional results

In this sub-section, we explore potential heterogeneities of the FFI-bank risk-taking nexus using additional analyses. First, we split our samples based on bank size, bank types and geographical region for an in-depth enquiry. Next, we investigate whether FFI- Bank risk-taking nexus has a differential effect in countries with diverse levels of market structure. Finally, we consider the interaction effect of FFI and institutional quality (IQ) to see the impact of IQ on the FFI-bank risk-taking nexus.

4.5.1. Additional result: Split sample (bank size, bank types and geographical region)

Results for the split sample based on size are shown in Table 4. Asset value of USD1 billion is considered as a cut-off point between large and small banks (Čihák and Hesse, 2010). For the bank types[8] (Table 5), we analyze conventional and Islamic banks – two large groups of banks form the sample. To investigate the difference across regions, we split our sample based on geographical regions[9], such as the EAP, ECA, MENA, SA and SSA (Table 6). We report the results into three time periods: full sample year, pre-IR4.0, post-IR4.0. We consider DRISK o proxy bank risk-taking.

The results in Table 4 suggest that big banks are more sensitive on the FFI – bank risk-taking nexus when compared to small banks. Large banks have experienced FFI – bank risk-taking nexus even during pre-IR4.0, which has only occurred during post-IR4.0 for the smaller banks. The result may raise serious concern on the competition among large and small banks centered towards 'investment in technology'. FFI - bank risk-taking nexus is heterogeneous among different bank types in the pre-IR4.0 period (Table 5) and turns homogenous at the post-IR4.0 era. Yet, conventional banks are more sensitive on the link between FFI and bank risk-taking than Islamic banks.

Banks' responses regarding the FFI -Bank risk-taking nexus are also heterogeneous among countries in different region and for the two regimes of IR4.0 (Table 6). More specifically, banks in SA and SSA countries are more sensitive when compared to banks in EAP, ECA and MENA countries. Growth of FFI is found to be faster in SA and SSA regions. Our findings are in the line with the study by Klapper and Hess (2019) which is collaborated by the International Finance Corporation (IFC) and the MasterCard Foundation. The report states that fast growth in financial inclusion among Sub-Saharan African countries is primarily fuelled by improvement of fintech-based financial services and innovative business models that include mobile and agent banking.

4.5.2. Additional result: FFI, bank risk-taking, and market structure

We further explore whether there is a differential effect in terms of levels of banking competition. In this regard, we use two measures of market structure. First is the net interest margin (NIM), which corresponds to the interest revenue as a share of its interest-bearing assets. The second measure is bank concentration, which is measured by the assets of the three largest banks as a share of assets of all banks. Higher (lower) value of these two measures represents less (more) competitive banking system. Both measures are based on the Financial Development and Structure Dataset (Beck et al., 2010).

Results from all four panels (Table 7) are consistent with the previous results. FFI reduces bank risk-taking even after controlling for competition. Coefficients are stronger and meaningful at the post-IR4.0 period, which signifies the impact of IR4.0 on risk-taking.

4.5.3. Additional result: FFI and institutional quality interaction

We consider the interaction effect of FFI and institutional quality (IQ) in Table 8. By following Ahamed and Mallick (2019), we coded higher institutional quality (IQ_H) with '1′, and '0′ for below average IQ. Lower institutional quality (IQ_L) is calculated by deducting IQ_H from '1′. While the impact of interaction (FFI and IQ) is bolder during the post-IR4.0 era, the impact is rather

Table 4
FFI - Bank risk-taking nexus by bank size.

Bank risk-taking: Default Risk (DRISK)						
	Full Sample Year (2011–2019)		Pre-IR4.0 (2011–2015)		Post-IR4.0 (2016–2019)	
	(1)	(2)	(3)	(4)	(5)	(6)
	Small banks	Big banks	Small banks	Big banks	Small banks	Big banks
FFI	−0.741***	−0.804***	0.388	−0.516**	−0.976***	−0.831***
	(0.239)	(0.120)	(0.523)	(0.224)	(0.278)	(0.148)
Obs.	1440	1525	584	677	856	848
R-squared	0.164	0.199	0.142	0.198	0.160	0.214
chi2	340.761***	425.411***	107.215***	199.627***	228.366***	283.548***
Control variables	yes	yes	yes	yes	yes	yes
Year fixed effect	yes	yes	no	no	no	no
Bank fixed effect	yes	yes	yes	yes	yes	yes

Note: This table shows the estimation results of the FFI-bank risk-taking nexus controlling the bank-specific and macroeconomic variables deploying the panel corrected standard (PCSE) estimation technique using the sample of full, pre- and post-IR4.0 period based on bank size. LS, DS, GTA, MQ, GDPG, INF, and IQ refer to loan share, deposit share, growth in total assets, management quality, GDP growth, inflation, and institutional quality respectively are used as control variables. FFI refers to fintech-based financial inclusion index (overall) is used as a main independent variable. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively and heteroskedastic panel corrected standard errors are in parenthesis. Sources: Orbis Bank Focus, WDI, WGI, FAS, Findex.

Table 5
FFI - Bank risk-taking nexus by bank types.

Bank risk-taking: Default Risk (DRISK)						
	Full Sample Year (2011–2019)		Pre-IR4.0 (2011–2015)		Post-IR4.0 (2016–2019)	
	(1)	(2)	(3)	(4)	(5)	(6)
	Conventional banks	Islamic banks	Conventional banks	Islamic banks	Conventional banks	Islamic banks
FFI	−0.853***	−0.548**	−0.540**	−0.135	−0.917***	−0.581*
	(0.123)	(0.238)	(0.243)	(0.371)	(0.147)	(0.315)
Obs.	2390	551	988	266	1402	285
R-squared	0.197	0.267	0.165	0.221	0.212	0.328
chi2	732.397***	234.635***	236.391***	100.053***	477.838***	155.582***
Control variables	yes	yes	yes	yes	yes	yes
Time fixed effect	yes	yes	no	no	no	no
Bank fixed effect	yes	yes	yes	yes	yes	yes

Note: This table demonstrates the estimation results of the FFI-bank risk-taking nexus controlling the bank-specific and macroeconomic variables deploying the panel corrected standard (PCSE) estimation technique using the sample of full, pre- and post-IR4.0 period based on bank types. SIZE, LS, DS, GTA, MQ, GDPG, INF, and IQ refer to bank size, loan share, deposit share, growth in total assets, management quality, GDP growth, inflation, and institutional quality respectively are used as control variables. FFI refers to fintech-based financial inclusion index (overall) is used as a main independent variable. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively and heteroskedastic panel corrected standard errors are in parenthesis. Sources: Orbis Bank Focus, WDI, WGI, FAS, Findex.

Table 6
FFI - Bank risk-taking nexus by geographical region.

Bank risk-taking: Default Risk (DRISK)										
	Pre-IR4.0 (2011–2015)					Post-IR4.0 (2016–2019)				
	(1)	(2)	**(3)**	**(4)**	**(5)**	(6)	(7)	(8)	(9)	(10)
	EAP	ECA	MENA	SA	SSA	EAP	ECA	MENA	SA	SSA
FFI	0.039	91.140	−54.823*	−2.475**	0.013	−0.552	4.974	−7.715	−2.845**	−0.772**
	(0.545)	(93.752)	(32.678)	(1.100)	(0.986)	(1.047)	(8.615)	(11.247)	(1.443)	(0.354)
Obs.	415	51	156	266	361	593	98	178	335	476
R-squared	0.084	0.121	0.145	0.154	0.031	0.170	0.111	0.134	0.135	0.137
Chi2	34.942	10.155	22.555	59.178	12.597	155.534	12.981	25.170	63.976	94.402
Control variables	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Time fixed effect	no	no	no	no	no	no	no	no	no	no
Bank fixed effect	no	no	no	no	no	no	no	no	no	no

Note: This table illustrates the estimation results of the FFI-bank risk-taking nexus controlling the bank-specific and macroeconomic variables deploying the panel corrected standard (PCSE) estimation technique using the sample of pre- and post-IR4.0 period based on geographical region. SIZE, LS, DS, GTA, MQ, GDPG, INF, and IQ refer to bank size, loan share, deposit share, growth in total assets, management quality, GDP growth, inflation, and institutional quality respectively are used as control variables. FFI denotes to fintech-based financial inclusion index (overall) is used as a main independent variable. EAP, ECA, MENA, SA and SSA indicate East Asia pacific, Europe and Central Asia, Middle East and North Africa, South Asia, and Sub-Saharan Africa correspondingly. *, **, and *** signify statistical significance at the 10%, 5%, and 1% levels, respectively and heteroskedastic panel corrected standard errors are in parenthesis. Sources: Orbis Bank Focus, WDI, WGI, FAS, Findex.

inconsistent for FACCESS – the supply side fintech index (Table 8). The negative coefficients in majority of the models indicate that FFI in countries with higher institutional quality helps reduce risk-taking by banks.

5. Conclusion

This paper examines the relationship between fintech-based financial inclusion (FFI) and the impact of the fourth industrial revolution (IR4.0) on bank risk-taking for a sample of 534 banks across 24 OIC countries over the 2011 – 2019 period. The findings suggest that Islamic banks are less risk-taking than conventional banks. Malaysia holds number one position in FFI and digital usage (FUSAGE) indices, while Bangladesh is ranked number one in digital access (FACCESS). Iraq and Chad are included in the segment of countries with the lowest score in all digital inclusion indices, meaning that people of these countries are highly digitally excluded.

The empirical evidence of FFI – bank risk-taking nexus advises that FFI is negatively associated with the levels of bank risk-taking for the overall sample countries among OIC. Additionally, IR4.0 strengthens the nexus regardless of the size and types of banks. This suggests that the nexus is less responsive in the pre-IR4.0 (prior to 2016). Banks in South Asian and Sub-Shahara African countries are more sensitive than others. The strong association between FFI and bank risk-taking suggests that FFI does not only reduce the risk-taking of the banks but also increases the financial mobility among the OIC countries. Consequently, FFI strategy ensures sustainable economic growth that is likely to help maintain financial sustainability in times of economic crisis. Our results are robust in multiple tests.

Table 7
FFI and bank risk-taking with different levels of market structure.

Bank risk-taking: Default Risk (DRISK)			
	Full Sample Year(2011–2019)	Pre-IR4.0(2011–2015)	Post-IR4.0(2016–2019)
	(1)	(2)	(3)
Panel A: Above average value of net interest margin (less competitive market)			
FFI	−0.963***	0.188	−1.091***
	(0.336)	(0.808)	(0.409)
Obs.	1108	472	636
R-squared	0.201	0.199	0.246
chi2	334.642	156.993	251.117
Control variables	yes	yes	yes
Time fixed effect	yes	no	no
Bank fixed effect	yes	yes	yes
Panel B: Below average value of net interest margin (more competitive market)			
FFI	−1.031***	−0.610***	−1.113***
	(0.127)	(0.236)	(0.152)
Obs.	1857	789	1068
R-squared	0.210	0.164	0.244
chi2	604.261	195.030	429.848
Control variables	yes	yes	yes
Time fixed effect	yes	no	no
Bank fixed effect	yes	yes	yes
Panel C: Above average value of bank concentration ratio (less competitive market)			
FFI	0.513	5.100	−0.710
	(1.226)	(27.376)	(1.858)
Obs.	443	195	248
R-squared	0.370	0.272	0.429
chi2	292.910	80.673	207.685
Control variables	yes	yes	yes
Time fixed effect	yes	no	no
Bank fixed effect	yes	yes	yes
Panel D: Below average value of bank concentration ratio (more competitive market)			
FFI	−0.803***	−0.400*	−0.852***
	(0.111)	(0.205)	(0.135)
Obs.	2522	1066	1456
R-squared	0.169	0.131	0.201
chi2	674.786	190.358	510.323
Control variables	yes	yes	yes
Time fixed effect	yes	no	no
Bank fixed effect	yes	yes	yes

Note: This table shows the estimation results of the FFI-bank risk-taking nexus while considering the different market structure (net interest margin and bank concentration) deploying the panel corrected standard (PCSE) estimation technique using the sample of full, pre-, and post-IR4.0 period. LS, DS, GTA, MQ, GDPG, INF, and IQ refer to loan share, deposit share, growth in total assets, management quality, GDP growth, inflation, and institutional quality respectively are used as control variables. FFI refers to fintech-based financial inclusion index (overall) is used as a main independent variable. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively and heteroskedastic panel corrected standard errors are in parenthesis. Sources: Orbis Bank Focus, WDI, WGI, FAS, Findex.

The results in principle report an above average penetration rate of FFI among OIC countries. FFI helps the banks reduce their default and leverage risk each respectively by 12.92% and portfolio risk by 7.99%. These results are further amplified with the introduction of IR4.0 since the year 2016. Banks gradually find it rewarding to get involved with technology as an essential interface between the bank and the customers. This has given a drive up to the opening of mobile banking, agent banking, and widespread internet banking. Morgan and Pontines (2018) have reported regulatory flexibility and competition as crucial causes behind this quick adoption of technology-assisted financial services.

Even though higher FFI translates into lower risk-taking, we forward this concern that as banks gradually engage in fintech-based intermediation, 'technology' will become a focal point of competition. Unless supervised prudently, larger banks may exert competitive pressure on smaller banks, resulting in system-wide financial instability. Effective use of FFI also depends on an increasing level of consumer literacy and protection. Several studies found the need for 'higher education level' and 'better legal protection' for stakeholders involved in FFI (Ahamed and Mallick, 2019). Our results on FFI-institutional quality interaction support that FFI-risk-taking nexus works better in countries with higher institutional quality. Hence, alongside investment in technological infrastructure, countries are expected to improve their footprints of institutional quality in order to get the best outcome of the FFI. Unless these components are integrated into digital inclusion policies, the promised reduction of asymmetric information will not be possible. Policymakers in respective jurisdictions can engage banks and customers using digital forums to develop such skills.

Along these lines, we believe that more studies are to be conducted on several relevant fronts. Impact of consumer privacy and literacy, mediated by FFI, on the bank sector stability would be a great dimension for future study. Studies may continue to explore how regulators would be able to arrest the 'size' anomaly that may promote unhealthy competition in fintech area. Future research

Table 8
FFI and institutional quality interaction and their impact on bank risk-taking.

Bank risk-taking: Default Risk (DRISK)									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Full Sample Year (2011–2019)			Pre-IR4.0 (2011–2015)			Post-IR4.0 (2016–2019)		
FFI × IQ_H (a)	−0.432***			−0.302**			−0.620***		
	(0.074)			(0.139)			(0.086)		
FFI × IQ_L (b)	−0.325			12.427*			−0.666		
	(0.758)			(6.729)			(0.904)		
FACCESS × IQ_H (a)		0.083			0.304*			−0.114	
		(0.093)			(0.183)			(0.120)	
FACCESS × IQ_L (b)		2.043*			7.349***			0.549	
		(1.122)			(2.548)			(1.390)	
FUSAGE × IQ_H (a)			−0.432***			−0.342**			−0.570***
			(0.072)			(0.138)			(0.082)
FUSAGE × IQ_L (b)			−0.574			13.003			−0.722
			(0.798)			(11.581)			(0.945)
Obs.	2965	2965	2965	1261	1261	1261	1704	1704	1704
R-squared	0.131	0.125	0.131	0.098	0.100	0.097	0.189	0.173	0.188
Chow testF statistics (a = b)	5.12	8.19	4.25	9.43	8.28	7.36	5.50	4.05	4.34
p value of F	0.02	0.00	0.04	0.00	0.00	0.01	0.02	0.04	0.03
Control variable	yes	yes	yes	yes	yes	yes	yes	yes	yes

Note: This table displays the estimation results of the interaction of FFI and institutional quality (IQ) impact on bank risk-taking using the sample of full, pre- and post-IR4.0 period deploying the panel corrected standard (PCSE) estimation technique following the revised model [Default risk = *f* (Fintech-based financial inclusion × IQ_H, Fintech-based financial inclusion × IQ_L, IQ_H, bank-specific variables, macro specific variables]. By following Ahamed and Mallick (2019), we consider IQ_H = 1 if the value of IQ is above average and zero otherwise. IQ_L is calculated 1 minus IQ_H. The null hypothesis of chow test suggests that the coefficients of a & b are similar (chow test is based on OLS model). FFI, FACCESS, FUSAGE refer to fintech-based financial inclusion index (overall), fintech-based financial inclusion index (access), and fintech-based financial inclusion index (usage) respectively. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively and heteroskedastic panel corrected standard errors are in parenthesis. Sources: Orbis Bank Focus, WDI, WGI, FAS, Findex.

may also take demographic and cultural characteristics of the users of fintech to examine the impact of the rate of technology adoption on consumer engagement by, inclusivity in, and stability of banks.

6. Note

1. World Economic Forum, https://www.weforum.org/focus/fourth-industrial-revolution
2. The FAS of IMF provides the year-wise data starting from 2004 but it has started to document data for mobile/internet banking (fintech-based data) from 2011 onward. On the other hand, Global Findex of the World Bank stores data from 2011 for the year 2011, 2014 and 2017, however, for our analysis we use linear interpolation to calculate FFI data for the missing years' data as we assume FFI experiences gradual growth.
3. The results of the PCA are available upon request.
4. The Worldwide Governance Indicators (WGI) project reports aggregate and individual governance indicators for over 200 countries and territories over the period 1996–2019, for six dimensions of governance namely, Control of Corruption, Government Effectiveness, Political Stability and Absence of Violence/Terrorism, Regulatory Quality, Rule of Law, and Voice and Accountability. The value of the six dimensions of governance ranges (-2.5 to + 2.5).
5. We also run regression using LRISK and PRISK; however, the results remain unchanged.
6. We also run two-step system Generalized Method of Moments (GMM) to minimise the endogeneity issue, to get unequivocal estimators and to see the dynamic relationship; however, our main findings remain unchanged. Results are available upon request.
7. We test the validity of the instrumental variables using the over-identification test by Hansen (1982) and the under-identification LM test by Kleibergen and Paap (2006).
8. We did not take cooperative and savings bank individually due to insufficient number of banks to produce separate results.
9. We also did not take LAC countries due to insufficient number of banks.

CRediT authorship contribution statement

Hasanul Banna: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Visualization, Writing – original draft. **M. Kabir Hassan:** Conceptualization, Validation, Supervision, Investigation, Writing – review & editing. **Mamunur Rashid:** Conceptualization, Investigation, Validation, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to

influence the work reported in this paper.

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Appendix A1. . The sample break-down based on country

Country Name	Number of banks	Number of observations	Sample %
Afghanistan	10	69	1.87
Albania	12	79	2.25
Bangladesh	56	416	10.49
Benin	8	52	1.50
Burkina Faso	12	67	2.25
Cameroon	11	69	2.06
Chad	5	21	0.94
Guinea	9	48	1.69
Guyana	6	42	1.12
Indonesia	114	816	21.35
Iraq	35	190	6.55
Jordan	19	159	3.56
Kyrgyz Republic	16	101	3.00
Malaysia	48	369	8.99
Mali	11	71	2.06
Mozambique	15	89	2.81
Niger	7	47	1.31
Nigeria	24	157	4.49
Pakistan	34	258	6.37
Qatar	11	92	2.06
Senegal	23	140	4.31
Sudan	22	129	4.12
Togo	7	42	1.31
Uganda	19	133	3.56
Total	534	3656	100

Note: This table shows the percentage of the bank sample used in this study based on country. Source: Author's compilation from the Orbis Bank Focus database

Appendix A2. . Selected variables for fintech-based financial inclusion index

Supply Side (Access to Digital Finance)	Demand Side (Usage of Digital Finance)
Mobile money agent, non-branch commercial bank agent outlets per 1,000 km^2 (AGTOUTKM) - Geographic penetration	Number of mobile and internet banking transaction (during reference year) per 1,000 adults (MITNTRANAD)
Mobile money agent, non-branch commercial bank agent outlets and POS (point of sale) terminals per 100,000 adults (AGTOUTAD) – Demographic penetration	Value of mobile and internet banking transaction (during reference year) (% of GDP) (MIVTRANSAD)
	Number of mobile money and e-money accounts per 1,000 adults (ACTAD)

Note: This table gives the list of selected variables and their definition to construct the fintech-based financial inclusion indices using principal component analysis (PCA). Source: IMF-FAS, Global Findex

Appendix A3. . Pairwise correlations and variance inflation factor

Variables	VIF	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	**(11)**
(1) FFI	1.60	1.000										
(2) FACCESS	1.55	0.243	1.000									
(3) FUSAGE	1.62	0.987	0.081	1.000								
(4) SIZE	1.30	0.314	0.122	0.302	1.000							

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Variables	VIF	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	**(11)**
(5) LS	1.51	0.172	0.218	0.140	0.215	1.000						
(6) DS	1.18	0.059	0.045	0.053	0.290	0.231	1.000					
(7) GTA	1.05	−0.062	0.090	−0.078	−0.054	−0.008	0.049	1.000				
(8) MQ	1.69	0.221	0.225	0.190	0.301	0.536	0.298	0.055	1.000			
(9) GDPG	1.27	0.203	0.225	0.190	0.301	0.536	0.298	0.055	1.000			
(10) INF	1.42	−0.239	0.043	−0.253	−0.019	−0.120	−0.104	0.010	−0.202	−0.086	1.000	
(11) IQ	2.37	0.545	−0.061	0.571	0.351	0.361	0.197	−0.035	0.468	0.078	−0.492	1.000
Mean VIF	1.49											

Note: This table displays the pairwise correlation and the variance inflation factor among the independent variables. FFI, FACCESS, FUSAGE, SIZE, LS, DS, GTA, MQ, GDPG, INF, IQ, and VIF refer to fintech-based financial inclusion index (overall), fintech-based financial inclusion index (access), fintech-based financial inclusion index (usage), bank size, loan share, deposit share, growth in total assets, management quality, GDP growth, inflation, institutional quality, and variance inflation factor respectively.

Appendix A4. . Robustness: PCSE regression

Bank risk-taking: Default Risk (DRISK)									
	Full Sample Year (2011–2019)			Pre-IR4.0 (2011–2015)			Post-IR4.0 (2016–2019)		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	FFI	FACCESS	FUSAGE	FFI	FACCESS	FUSAGE	FFI	FACCESS	FUSAGE
FFI	−0.764***	−0.667***	−0.732***	−0.293	−0.333	−0.268	−0.895***	−0.547***	−0.889***
	(0.098)	(0.138)	(0.099)	(0.179)	(0.217)	(0.182)	(0.117)	(0.190)	(0.118)
SIZE	−0.103***	−0.119***	−0.105***	−0.036	−0.042*	−0.037	−0.159***	−0.183***	−0.160***
	(0.016)	(0.016)	(0.016)	(0.024)	(0.024)	(0.024)	(0.021)	(0.021)	(0.021)
LS	−0.530***	−0.335*	−0.548***	0.225	0.312	0.225	−0.840***	−0.697***	−0.873***
	(0.168)	(0.171)	(0.169)	(0.264)	(0.264)	(0.264)	(0.222)	(0.230)	(0.222)
DS	0.812***	0.843***	0.841***	0.818***	0.837***	0.832***	0.812***	0.895***	0.847***
	(0.177)	(0.181)	(0.177)	(0.279)	(0.281)	(0.278)	(0.231)	(0.241)	(0.230)
GTA	−0.332**	−0.289**	−0.329**	−0.298	−0.269	−0.294	−0.560***	−0.499***	−0.568***
	(0.138)	(0.138)	(0.138)	(0.202)	(0.199)	(0.202)	(0.183)	(0.185)	(0.183)
MQ	−0.899***	−0.666***	−0.891***	−1.447***	−1.374***	−1.437***	−0.418	−0.105	−0.424
	(0.228)	(0.222)	(0.228)	(0.346)	(0.340)	(0.346)	(0.308)	(0.302)	(0.310)
GDPG	0.004	0.028*	−0.003	−0.018	−0.011	−0.019	0.006	0.023	−0.003
	(0.015)	(0.016)	(0.015)	(0.024)	(0.025)	(0.024)	(0.020)	(0.022)	(0.020)
INF	−0.004	0.011	−0.006	−0.017	−0.011	−0.018	−0.005	0.011	−0.008
	(0.007)	(0.008)	(0.007)	(0.012)	(0.012)	(0.012)	(0.010)	(0.010)	(0.010)
IQ	0.114**	0.037	0.100**	−0.050	−0.064	−0.058	0.181***	0.057	0.170**
	(0.049)	(0.047)	(0.049)	(0.074)	(0.071)	(0.073)	(0.068)	(0.066)	(0.068)
Obs.	2965	2965	2965	1261	1261	1261	1704	1704	1704
R-squared	0.198	0.190	0.197	0.161	0.161	0.161	0.228	0.208	0.227
chi2	910.799***	822.672***	903.269***	301.184***	300.734***	300.469***	643.810***	519.031***	643.813***
Time fixed effect	yes	yes	yes	no	no	no	no	no	no
Bank fixed effect	yes	yes	yes	yes	yes	yes	yes	yes	yes

Note: This table shows the estimation results of the FFI-bank risk-taking nexus controlling the bank-specific and macroeconomic variables deploying the panel corrected standard (PCSE) estimation technique using the sample of full, pre- and post-IR4.0 period. FFI, FACCESS, FUSAGE, SIZE, LS, DS, GTA, MQ, GDPG, INF, and IQ refer to fintech-based financial inclusion index (overall), fintech-based financial inclusion index (access), fintech-based financial inclusion index (usage), bank size, loan share, deposit share, growth in total assets, management quality, GDP growth, inflation, and institutional quality respectively. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively and heteroskedastic panel corrected standard errors are in parenthesis. Sources: Orbis Bank Focus, WDI, WGI, FAS, Findex.

Appendix A5. . Robustness: Two-stage least square instrument variable regression (2SLS-IV)

Bank risk-taking: Default Risk (DRISK)									
	Full Sample Year (2011–2019)			Pre-IR4.0 (2011–2015)			Post-IR4.0 (2016–2019)		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	FFI	FACCESS	FUSAGE	FFI	FACCESS	FUSAGE	FFI	FACCESS	FUSAGE
FFI	−0.797***	−0.758***	−0.684***	−0.026	−0.349	0.056	−0.649***	−0.699**	−0.620***
	(0.176)	(0.203)	(0.174)	(0.225)	(0.246)	(0.225)	(0.206)	(0.272)	(0.208)

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Bank risk-taking: Default Risk (DRISK)									
	Full Sample Year (2011–2019)			Pre-IR4.0 (2011–2015)			Post-IR4.0 (2016–2019)		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
SIZE	−0.067**	−0.073**	−0.071**	−0.041	−0.037	−0.043	−0.130***	−0.144***	−0.131***
	(0.029)	(0.029)	(0.029)	(0.033)	(0.032)	(0.033)	(0.036)	(0.035)	(0.036)
LS	−0.493*	−0.348	−0.512*	−0.020	0.013	−0.010	−0.691**	−0.539*	−0.712**
	(0.293)	(0.301)	(0.293)	(0.333)	(0.337)	(0.334)	(0.314)	(0.326)	(0.314)
DS	0.908***	0.886***	0.943***	0.901**	0.824**	0.923**	1.003***	0.964***	1.031***
	(0.290)	(0.297)	(0.291)	(0.366)	(0.372)	(0.367)	(0.331)	(0.339)	(0.330)
GTA	−0.072	−0.071	−0.068	−0.192	−0.206	−0.181	−0.121	−0.081	−0.124
	(0.143)	(0.142)	(0.143)	(0.197)	(0.191)	(0.198)	(0.165)	(0.165)	(0.165)
MQ	−0.835**	−0.733**	−0.830**	−1.189***	−1.190***	−1.169***	−0.322	−0.180	−0.325
	(0.338)	(0.336)	(0.338)	(0.433)	(0.425)	(0.433)	(0.413)	(0.405)	(0.414)
GDPG	0.019	0.035*	0.013	−0.063***	−0.059**	−0.063***	0.035*	0.047**	0.032*
	(0.019)	(0.019)	(0.019)	(0.024)	(0.025)	(0.024)	(0.019)	(0.019)	(0.019)
INF	−0.006	0.001	−0.007	−0.015	−0.012	−0.015	0.005	0.015	0.005
	(0.011)	(0.011)	(0.011)	(0.015)	(0.015)	(0.015)	(0.013)	(0.013)	(0.013)
IQ	0.038	−0.036	0.014	−0.114	−0.081	−0.129	0.007	−0.052	−0.007
	(0.083)	(0.078)	(0.082)	(0.105)	(0.099)	(0.103)	(0.101)	(0.096)	(0.100)
Obs.	2706	2706	2706	1145	1145	1145	1561	1561	1561
R-squared	0.1836	0.1756	0.1826	0.1484	0.1479	0.1478	0.2103	0.1971	0.2089
chi2	373.542***	366.842***	366.977***	168.573***	165.809***	170.264***	240.491***	211.169***	239.998***
Time fixed effect	yes	yes	yes	no	no	no	no	no	no
Bank fixed effect	yes	yes	yes	yes	yes	yes	yes	yes	yes

Note: This table displays the estimation results of the FFI-bank risk-taking nexus controlling the bank-specific and macroeconomic variables deploying the two stage least square instrumental variable (2SLS-IV) estimation technique using the sample of full, pre- and post-IR4.0 period. FFI, FACCESS, FUSAGE, SIZE, LS, DS, GTA, MQ, GDPG, INF, and IQ refer to fintech-based financial inclusion index (overall), fintech-based financial inclusion index (access), fintech-based financial inclusion index (usage), bank size, loan share, deposit share, growth in total assets, management quality, GDP growth, inflation, and institutional quality respectively. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively and heteroskedastic panel corrected standard errors are in parenthesis. Sources: Orbis Bank Focus, WDI, WGI, FAS, Findex.

Appendix A6. . Robustness: Quantile regression

Bank risk-taking: Default Risk (DRISK)									
	1	2	3	4	5	6	7	8	9
Quantile	Q10	Q20	Q30	Q40	Q50	Q60	Q70	Q80	Q90
Full Sample Year (2011–2019)									
FFI	−0.174	−0.417**	−0.581***	−0.641***	−0.653***	−0.744***	−0.847***	−1.082***	−1.458***
	(0.249)	(0.186)	(0.149)	(0.141)	(0.091)	(0.107)	(0.120)	(0.154)	(0.214)
Obs.	2965	2965	2965	2965	2965	2965	2965	2965	2965
Pseudo R-squared	0.0817	0.0977	0.1073	0.1084	0.1199	0.1317	0.1399	0.1554	0.1870
Control variables	yes	yes	yes	yes	yes	yes	yes	yes	yes
Time fixed effect	yes	yes	yes	yes	yes	yes	yes	yes	yes
Bank fixed effect	yes	yes	yes	yes	yes	yes	yes	yes	yes
Pre-IR4.0 (2011–2015)									
FFI	0.276	0.040	−0.180	−0.115	−0.247	−0.364**	−0.460***	−0.617***	−0.902***
	(0.299)	(0.301)	(0.220)	(0.257)	(0.176)	(0.163)	(0.173)	(0.215)	(0.299)
Obs.	1261	1261	1261	1261	1261	1261	1261	1261	1261
Pseudo R-squared	0.0602	0.0860	0.1028	0.1064	0.1091	0.1181	0.1176	0.1116	0.1275
Control variables	yes	yes	yes	yes	yes	yes	yes	yes	yes
Time fixed effect	no	no	no	no	no	no	no	No	no
Bank fixed effect	yes	yes	yes	yes	yes	yes	yes	yes	yes
Post-IR4.0 (2016–2019)									
FFI	−0.356*	−0.418**	−0.575**	−0.729***	−0.684***	−0.906***	−1.032***	−1.258***	−1.734***
	(0.214)	(0.187)	(0.255)	(0.192)	(0.142)	(0.180)	(0.168)	(0.172)	(0.225)
Obs.	1704	1704	1704	1704	1704	1704	1704	1704	1704
Pseudo R-squared	0.0895	0.1011	0.1088	0.1139	0.1341	0.1504	0.1682	0.2031	0.2238
Control variables	yes	yes	yes	yes	yes	yes	yes	yes	yes
Time fixed effect	no	no	no	no	no	no	no	no	no
Bank fixed effect	yes	yes	yes	yes	yes	yes	yes	yes	yes

Note: This table gives the estimation results of the FFI-bank risk-taking nexus controlling the bank-specific and macroeconomic variables deploying the quantile regression (QE) estimation technique using the sample of full, pre- and post-IR4.0 period. The 10th

percentile to 90th percentile have been used. SIZE, LS, DS, GTA, MQ, GDPG, INF, and IQ refer to bank size, loan share, deposit share, growth in total assets, management quality, GDP growth, inflation, and institutional quality respectively are used as control variables. FFI refers to fintech-based financial inclusion index (overall) is used as a main independent variable. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively and heteroskedastic panel corrected standard errors are in parenthesis. Sources: Orbis Bank Focus, WDI, WGI, FAS, Findex.

Appendix A7. . Robustness: Alternative proxy: Bank risk-taking and FFI

Bank risk-taking: Default Risk (DRISK) and Non-performing Loans Ratio (NPL)Fintech-based Financial Inclusion (FFI): FFI and Made or received digital payments (DP)			
	(1)	(2)	(3)
	Full Sample Year (2011–2019)	Pre-IR4.0 (2011–2015)	Post-IR4.0 (2016–2019)
Panel A: Alternative bank risk-taking proxy - NPL			
FFI	−1.827**	−0.503	−3.682***
	(0.730)	(1.012)	(1.235)
Obs.	2010	1066	944
R-squared	0.257	0.170	0.276
Chi2	853.592	253.225	359.374
Control variables	yes	yes	yes
Time fixed effect	yes	no	no
Bank fixed effect	yes	yes	yes
Panel B: Alternative FFI proxy - DP			
DP	−0.006***	0.005	−0.009***
	(0.002)	(0.003)	(0.002)
Obs.	2706	1145	1561
R-squared	0.179	0.154	0.206
Chi2	722.313	253.555	501.818
Control variables	yes	yes	yes
Time fixed effect	yes	no	no
Bank fixed effect	yes	yes	yes

Note: This table provides the estimation results of the FFI-bank risk-taking nexus controlling the bank-specific and macroeconomic variables deploying the panel corrected standard (PCSE) estimation technique using the sample of full, pre- and post-IR4.0 period as well as using alternative proxies for bank risk-taking (Panel A) and FFI index (Panel B). SIZE, LS, DS, GTA, MQ, GDPG, INF, and IQ refer to bank size, loan share, deposit share, growth in total assets, management quality, GDP growth, inflation, and institutional quality respectively are used as control variables. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively and heteroskedastic panel corrected standard errors are in parenthesis. Sources: Orbis Bank Focus, WDI, WGI, FAS, Findex.

Appendix A8. . Robustness: FFI and IR4 interaction and their impact on bank risk-taking

Bank risk-taking: Default Risk (DRISK)				
	(1)	(2)	(3)	(4)
	FFI	FACCESS	FUSAGE	DP
FFI	−0.466***	−0.411**	−0.468***	−0.000
	(0.139)	(0.191)	(0.140)	(0.002)
IR4.0	0.225***	0.182***	0.201***	0.366***
	(0.049)	(0.049)	(0.047)	(0.084)
FFI × IR4.0	−0.346**			
	(0.137)			
FACCESS × IR4.0		−0.107		
		(0.177)		
FUSAGE × IR4.0			−0.314**	
			(0.135)	
DP × IR4.0				−0.007***
				(0.002)
Obs.	2965	2965	2965	2706
R-squared	0.191	0.180	0.189	0.173
chi2	864.173	770.371	858.927	694.303
Control variable	yes	yes	yes	yes
Time fixed effect	no	no	no	no
Bank fixed effect	yes	yes	yes	yes

Note: This table displays the estimation results of the FFI-bank risk-taking nexus controlling the 4th industrial revolution (IR4.0) dummy, bank-specific and macroeconomic variables deploying the panel corrected standard (PCSE) estimation technique. SIZE, LS,

DS, GTA, MQ, GDPG, INF, and IQ refer to bank size, loan share, deposit share, growth in total assets, management quality, GDP growth, inflation, and institutional quality respectively are used as control variables. FFI, FACCESS, FUSAGE refer to fintech-based financial inclusion index (overall), fintech-based financial inclusion index (access), and fintech-based financial inclusion index (usage) respectively and their interaction with IR4.0 are used as main independent variables. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively and heteroskedastic panel corrected standard errors are in parenthesis. Sources: Orbis Bank Focus, WDI, WGI, FAS, Findex.

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