FinTech developments and their heterogeneous effect on digital finance for SMEs and entrepreneurship: evidence from 47 African countries

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Abstract

Purpose – Lack of access to finance is a major constraint to the growth of small and medium-sized enterprises (SMEs) and entrepreneurship in developing countries. The recent proliferation of mobile phone services, access to the internet and emerging technologies has led to a surge in the use of FinTech in Africa and is transforming the financial sector. This paper aims to examine whether FinTech developments heterogeneously contribute to the growth of digital finance for SMEs and entrepreneurship in 47 African countries from 2013 to 2020.

Design/methodology/approach – The paper uses a novel method of moments quantile regression, which deals with heterogeneity and endogeneity in diverse conditions for asymmetric and nonlinear models.

Findings – The empirical results reveal that the rise of FinTech companies offering services in Africa heterogeneously increases digital finance for SMEs and entrepreneurship in their different stages of growth. FinTech developments have a strong and positive impact in countries with higher levels of digital finance than those with lower levels. FinTech developments and digital finance positively and significantly influence entrepreneurship in Africa, particularly in the nascent and transitional development stages of entrepreneurship. Institutional quality has a considerable positive moderating effect when used as a control rather than an interaction variable.

Practical implications – The results suggest the need to promote FinTech developments in Africa: to provide a wide range of alternative digital finance schemes to SMEs and to promote entrepreneurship, especially in countries where entrepreneurship is in the nascent and transitional development stages. The results also underscore the need to promote FinTech development through supportive regulations and institutional quality to reduce risks related to FinTech and digital financing schemes.

JEL classification – G20, G21, G23, O30, O50

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Originality/value – To the best of the authors' knowledge, this paper is one of the first attempts to account for the often overlooked heterogeneity effects and show that the influence of FinTech developments is not homogenous across the varying development stages of digital finance and entrepreneurship.

Keywords FinTech development, Digital finance, SME financing, Entrepreneurship

Paper type Research paper

1. Introduction

The financing of small and medium-sized enterprises (SMEs) and entrepreneurs continues to receive attention among development partners, technology companies, policymakers and regulators, academia and the financial sector, particularly in Africa. About 90% of African enterprises are SMEs, contributing at least 30% of GDP and 80% of employment in informal and formal sectors (London Stock Exchange Group, 2018). As of 2018, there were 48.2 million informal and formal SMEs in Africa, compared to 17.2 million in Latin America and the Caribbean (LAC) (SME Finance Forum, 2018). However, compared to other developing regions, Africa has the highest percentage of financially constrained SMEs at 52%, whereas other comparable developing regions such as LAC are at 22% (SME Finance Forum, 2018). Access to finance significantly impacts the growth of SMEs and entrepreneurship (Moreira, 2016; Qin and Kong, 2022). Entrepreneurs and SMEs in developing countries are characterised by information opacity, which makes it difficult for financiers to assess their creditworthiness.

In recent years, there has been a growing interest among development partners, policymakers, practitioners and researchers in understanding the potential effect of financial technology (FinTech [1]) and emerging technologies in unlocking financing for entrepreneurship and SMEs. FinTech developments are increasing the gathering and sharing of information, changing how funds are mobilised and allocated and increasing capital-raising activities. The advancements of FinTech are also influencing the proliferation of alternative financing schemes (*digital finance* [2] in particular) that are distinct from traditional banking and capital markets. The credit market landscape is becoming competitive, with traditional banks, alternative financiers and new entrants actively using FinTech. The recent proliferation of mobile phone services, access to the internet and emerging technologies have led to a surge in the use of FinTech in Africa and are transforming the financial sector. In 2019, sub-Saharan Africa (SSA) exceeded the US$1bn threshold for digital finance (Cambridge Centre for Alternative Finance, 2021). However, their effect on SME financing and entrepreneurship has received less scholarly consideration in Africa. Thus, this paper explores the following research questions:

RQ1. To what extent have FinTech developments heterogeneously increased digital finance for SMEs in Africa?

RQ2. Do FinTech developments heterogeneously contribute to the growth of entrepreneurship in Africa?

RQ3. To what extent do digital finance schemes for SMEs heterogeneously influence entrepreneurship development in Africa?

RQ4. To what extent do institutional qualities moderate the impact of FinTech developments on different levels of digital finance for SMEs and entrepreneurship in Africa?

To our knowledge, this is the first attempt in Africa to analyse the effect of FinTech developments and their implication on digital finance for SMEs and entrepreneurship using emergent cross-sectional data of FinTech development and digital finance from the Cambridge Centre for Alternative Finance (CCAF [3]) database over the period 2013–2020.

Despite the growing literature on FinTech and SME financing globally, very few studies are empirical (Farag and Johan, 2021; Sanga and Aziakpono, 2023a). Second, there is a shortage of longitudinal empirical studies on FinTech and SME financing. Out of the 62 global studies reviewed by Sanga and Aziakpono (2023a), only five used country-level data (Abdeldayem and Aldulaimi, 2021; Dikaputra *et al.*, 2019; Hodula, 2022; Lorenz and Pommet, 2021; Rijanto, 2022). The remaining studies are limited to a case study, specific country or platform. Third, despite the rise of FinTech companies operating in Africa, empirical studies examining their effect on digital finance for SMEs and entrepreneurship in Africa are pretty scanty. For example, out of 62 global empirical publications on FinTech and SME financing for 2008–2022 (Sanga and Aziakpono, 2023a), only five were conducted in Africa and have limited coverage and scope. Three of those empirical studies (Islam *et al.*, 2018; Lorenz and Pommet, 2021; Mdoe and Kinyanjui, 2018) focus on mobile money and lending to SMEs in East African countries. The other two (Kazaure *et al.*, 2021; Ochinanwata *et al.*, 2021) explore reasons for SMEs' adoption of crowd-funding in Nigeria. Finally, the reviewed empirical literature has not addressed the heterogeneity effects, which in this paper are referred to as different effects of FinTech developments across varying development stages of digital finance and entrepreneurship. Understanding the heterogeneous results is essential for policymakers in devising appropriate interventions depending on the level of development of digital finance and entrepreneurship. Focusing only on the central tendencies using conventional linear regression methods leaves the essential insights of the relationships hidden when we are interested in knowing the heterogeneity of the relationships at the nascent, transitional and mature stages (further discussion on the heterogeneity effects of FinTech developments is presented in Section 4.2).

In recognition of these limitations, this paper contributes to the literature in several ways. First, we examine to what extent the rising FinTech companies operating in Africa may have increased digital finance for SMEs in 47 African countries. Second, we investigate the impact of FinTech development on entrepreneurship in 30 African countries. Third, we analyse the extent to which digital finance schemes for SMEs influence entrepreneurship in 30 African countries. Fourth, we determine the heterogeneity effects of FinTech developments on different levels of digital finance and entrepreneurship. In doing so, we are interested in knowing the heterogeneous effects through various conditional quantile estimates across the distribution of digital finance and entrepreneurship. This is important because the new insights and information from the heterogeneous effects can help devise appropriate policies that promote FinTech development in different African countries. Fifth, we scrutinise the moderating effects of institutional quality in each case above. Finally, we provide focused policy recommendations. As far as we are aware, this is also the first paper to account for the often overlooked heterogeneity effects of FinTech developments across the varying distribution of digital finance and entrepreneurship by using the novel method of moments quantile regression (MMQR) of Machado and Santos Silva (2019). Besides dealing with heterogeneity and endogeneity, MMQR is considered the most robust estimation method in diverse conditions for asymmetric and nonlinear models (An *et al.*, 2021; Ike *et al.*, 2020).

The findings show that, first, the rise of FinTech companies offering services in Africa has significantly increased digital financing delivered to SMEs. The impact is more prevalent in countries with higher levels of digital finance than in those with lower levels. Second, FinTech developments and digital finance have a positive and statistically significant impact on entrepreneurship in Africa. Their influence is more dominant in countries with low entrepreneurship levels or in a nascent and developing stage. Finally, institutional qualities have a considerable moderating effect on FinTech and digital financing when used as a control rather than an interaction variable. Thus, policymakers who play a vital role in supporting SMEs and

entrepreneurs who often face challenges in accessing traditional financing options can implement policies that:

- Foster the development of FinTech and inclusive digital financing solutions in Africa, especially in countries where there is high level of digital finance extended to SMEs.
- Promote FinTech development and digital finance in countries where entrepreneurship is at the initial and transitional development stages.

The rest of this paper proceeds as follows. Section 2 provides the theoretical considerations. Section 3 presents a literature review. Sections 4 and 5, respectively, discuss the research methodology and results. Finally, Section 6 provides the conclusion, policy recommendations and limitations.

2. Theoretical considerations and hypotheses development

Information asymmetry and financial intermediation theories underpin the financing of SMEs and entrepreneurship. Credit market equilibrium is always affected by information asymmetry (Besanko and Thakor, 1987; Stiglitz and Weiss, 1981). Thus, financial intermediation deals with the transfer of risk and cost of transactions due to information asymmetry and market imperfections (Allen and Santomero, 1998). Information asymmetry leads to adverse selection in assessing borrowers (*ex-ante* moral hazards) and monitoring borrowers' projects (*ex-post* moral hazards) (Stiglitz and Weiss, 1981). The traditional financing models address the information asymmetry through relationship lending (Boot, 2000; Liberti and Petersen, 2019; Petersen and Rajan, 1995), credit rationing (Stiglitz and Weiss, 1981), increased cost of borrowing and demand for collateral and guarantee to cover the loss in case of default (Besanko and Kanatas, 1993; Besanko and Thakor, 1987; Diamond, 1984). Apart from transactional risks and costs, under market imperfections, there are also costs associated with acquiring information (Ncube, 2007). These costs are related to financial intermediation and the production of information for assessing and monitoring SMEs and entrepreneurs to reduce adverse selection and moral hazard problems. That is why interest rate mark-ups on SMEs' loans in developing countries are higher than in developed countries, mainly due to SMEs' information opaqueness (Beck *et al.*, 2011; Berger *et al.*, 2001; Brei *et al.*, 2020).

2.1 FinTech developments and digital finance for small and medium-sized enterprises

FinTech developments have created a new dynamic of disintermediation known as *alternative financing schemes*, whereby savers can now deal with investors directly with reduced transaction costs and information asymmetry. Unlike traditional financing models, which use their equity and funding raised through securitisation, alternative financing schemes are based on the agency model, which does not retain risk on their balance sheet, generates revenue from fees, and therefore does not need capital adequacy and reserve regulations like banks (Navaretti *et al.*, 2018; Thakor, 2020). Alternative financing schemes are based on big data and decentralised matching of lenders and borrowers, while long-term relationships and a history of transactions drive bank-based lending. The paper focuses on digital finance as one of the alternative financing schemes. Digital finance relates to a wide range of digital lending and capital-raising options available to SMEs, such as marketplace (peer-to-peer) lending (P2P), crowd-funding, crowd-lending, crowd-investing, initial coin offerings (ICOs), blockchain-based securities and lending systems, mobile money and credit schemes, big data and analytics-based financing and artificial intelligence (AI)-based credit schemes. Second, FinTech has the potential to help financiers mitigate SMEs' credit risks associated with information asymmetry and lack of collateral, but it can also reduce lenders' cost and time to collect information and assess SMEs' creditworthiness (Abbasi *et al.*, 2021; Larios-Hernandez, 2017). Financially constrained and innovative SMEs are likely to seek digital

finance schemes because they are easier to access with simple and rapid lending processes and have flexible loan amounts with lower transactional costs and lending rates compared to traditional banks, among others (Purnamasari *et al.*, 2020; Rokhim *et al.*, 2021; Rosavina *et al.*, 2019; Spatia *et al.*, 2021; Temelkov and Samonikov, 2018; Xiang *et al.*, 2021). Based on FinTech's capabilities in creating alternative financing schemes and mitigating SMEs' information opacity, it is expected that FinTech developments will promote more digital finance schemes for SMEs:

H1. FinTech developments heterogeneously increase digital finance for SMEs in Africa.

2.2 FinTech developments and entrepreneurship

Start-ups and small businesses face challenges accessing financing from financial institutions because they have a history of transactions. Entrepreneurial activities are constrained by a lack of financing and a conducive business environment (Beck and Demirgüç-Kunt, 2006; Brixiova, 2013). FinTech has increased the accessibility and affordability of financial services and products, reduced the cost and time to collect information and assess borrowers, reduced infrastructure and operational expenses (Chen, 2020; Cull *et al.*, 2018) and broadened lending techniques and geographical outreach (Cull *et al.*, 2018; Sanga and Aziakpono, 2022). Thus, distant entrepreneurs from traditional financial institutions can access affordable financial services and products through mobile phones and agents' services. Second, FinTech developments have increased payment methods, removing geographical limitations between entrepreneurs and their clients. This payment convenience has increased the customer base for entrepreneurs and SMEs through online sales. Thus, FinTech has the potential to foster entrepreneurship because of the easiness of access to markets and easy and less costly digital payment methods (Huang *et al.*, 2023). Third, FinTech enables entrepreneurs to build transaction history and digital footprints over time by using digital payment methods (Berg *et al.*, 2020), which can be used to access more financing in future. Finally, FinTech developments can overcome the entrepreneurs' information asymmetry problem through credible online verification of information, social networks and big data [4] (Shah *et al.*, 2022; Shao *et al.*, 2022; Song *et al.*, 2021; Wang *et al.*, 2020). Based on FinTech's capabilities to increase the accessibility and affordability of financial services to entrepreneurs, it is expected that FinTech development will promote entrepreneurship in Africa:

H2. FinTech developments heterogeneously facilitate the growth of entrepreneurship in Africa.

2.3 Digital finance for small and medium-sized enterprises and entrepreneurship

The empirical evidence shows that digital finance is significantly overcoming the limitations of traditional financing to SMEs and entrepreneurs (Chen and Yoon, 2022; Xie and Liu, 2022; Zhang *et al.*, 2022; Zhang *et al.*, 2023) and is substantially expanding in financial markets where SMEs and entrepreneurs are less likely to be reached by traditional banks (Barkley and Schweitzer, 2021; Gopal and Schnabl, 2022). Second, digital finance can widen access to finance and promote innovation and industrial upgrading (Zapata-Cantu *et al.*, 2023). Thus, digital finance can potentially stimulate entrepreneurship through increased access to financing that enables SMEs to pursue different entrepreneurial activities:

H3. Digital finance for SMEs heterogeneously influences entrepreneurship development in Africa.

2.4 Institutional quality and FinTech development

Finally, despite the benefits of FinTech in promoting SME financing, there are potential risks associated with FinTech, which may be due to poor regulation. These risks include fraudulent capital-raising activities, misappropriation of assets in crowd-investing, information monopoly and overload, biases stemming from the use of big data and analytics, default, illiquidity, cyberattacks, lack of transparency and access inequality (Frost *et al.*, 2019; Hua and Huang, 2021; Jagtiani and John, 2018). Fraudulent and illegal FinTech transactions may create systemic risk because the risks can spread quickly and broader due to many participants scattered in different geographical areas. The case examples of fraudulent and illegal FinTech activities were observed in emerging economies by Kharisma (2021) in Indonesia, Chatterjee (2019) in India and Hua and Huang (2021) in China. These authors argue that if such risks are not mitigated, this could erode FinTech's potential gains and affect consumer protection and financial stability. In most African countries, digital finance schemes are either unregulated, casually regulated, fully regulated or prohibited. The discussed FinTech risks and unregulated FinTech activities may negatively impact the financial system and disrupt competition in small business lending (Jagtiani and John, 2018; Jagtiani and Lemieux, 2016). The empirical evidence shows that regulations increase stability and transparency and reduce risks for digital finance and online credit markets (Zhang *et al.*, 2022). Furthermore, empirical evidence indicates that institutional qualities create a level playing field in financial markets (Herger *et al.*, 2008) and were found to influence financial deepening in Africa (Sanga and Aziakpono, 2023b). Institutional qualities and regulations can support or suppress financial innovation and expansion of digital finance. Thus, the interaction of FinTech development and institutional quality may positively or negatively affect digital financing for SMEs and entrepreneurship. We use institutional qualities to test the mediating effect of FinTech developments on digital finance for African SMEs and entrepreneurship:

H4. The interaction of FinTech development and institutional quality may positively or negatively affect digital finance for SMEs and entrepreneurship.

3. Literature review

This literature review is organised into four strands based on the relationships defined in Section 2 and the conceptual framework shown in Figure 1.

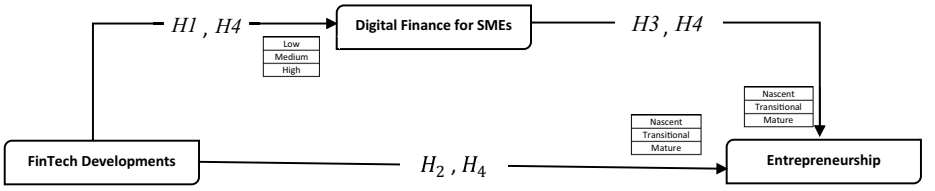


Figure 1. Conceptual framework

Source: Authors' own work

3.1 FinTech developments and digital finance for small and medium-sized enterprises

This strand of literature posits that FinTech developments help mitigate information asymmetry and reduce transaction costs, thus alleviating financing constraints for SMEs. Xiao *et al.* (2022) found that blockchain-driven supply chain finance addresses the financing problems of SMEs by reducing the information asymmetry in China. The authors used the entropy weight method [5] to analyse the supply chain operations of SMEs in the manufacturing industry. Shao *et al.* (2022) examined the effect of AI finance on non-state-owned firms using a cash flow sensitivity model, which is the interaction of changes in cash holding and the digital finance inclusive index (as a proxy of AI finance). The authors established that AI finance alleviates financing constraints for small, non-state-owned firms in China. Lin *et al.* (2022) found that digital finance reduces two-way information asymmetry between lenders and borrowers, alleviates financing constraints and promotes the investment behaviour of micro and small enterprises. The authors used probit and binomial regressions to analyse the dummy of digital payment from FinTech companies as a proxy for digital finance. Zhang *et al.* (2022) examined the provincial data in China using fixed effects and 2SLS and showed that FinTech promotes direct financing to SMEs and increases financial disintermediation in China. The authors constructed a regional FinTech indicator using FinTech applications, industry and environment index. Yao and Yang (2022) analysed SME data from the Chinese growth enterprise market and found that digital finance alleviates financing constraints and stimulates innovations among SMEs. Several studies used the China Stock Market and Accounting Research (CSMAR) database and digital finance index from the Digital Finance Research Centre of Peking University. For example, Xia *et al.* (2022) found that digital finance increases SMEs' access to bank debt financing, reduces financing costs and constraints and reduces SMEs' resilience to other shocks such as COVID-19. The authors also used the number of provincial Fintech companies to measure digital finance for robustness check. Other empirical studies that found similar results in China that digitally alleviate financing constraints include Chen and Yoon (2022), Li *et al.* (2022a) and Huang *et al.* (2022). Song *et al.* (2021) established that digital platforms using big data analytics helped SMEs in China to obtain supply chain finance. These findings were obtained after analysing data in the mobile production industry using neural network algorithms and multiple regressions.

These former studies focus on China only. There are a few studies from other regions. Rijanto (2022) found that SMEs can use crowdfunding with the success of 44% of fundraising targets in creative industries in seven Southeast Asian countries using OLS. Using OLS, Eldridge *et al.* (2021) established that crowd-investing significantly impacts SME financing, performance and growth in the UK after analysing SME data sourced from Crowdcube and Techcrunch for 2014–2020. Using mobile money and mobile banking increases SMEs' probability of accessing informal and formal credit in Kenya (Mdoe and Kinyanjui, 2018). Using 2012–2013 data from World Bank Enterprise Surveys and 2SLS and bivariate probit model, Lorenz and Pommet (2021) found that using mobile money by small businesses in East Africa helps reduce credit constraints.

3.2 FinTech developments and entrepreneurship

Few empirical studies explore the relationship between FinTech development and entrepreneurship. Yue *et al.* (2023) used multiple regression methods (SYS-GMM, PSM and 2SLS) to analyse data from Wind and CSMAR databases from 2011 to 2021. The authors measured corporate innovation and entrepreneurship by number of patent applications. Their analysis revealed that FinTech developments significantly influence corporate innovation and alleviate corporates' financing constraints, leading to the growth of

corporate entrepreneurship in China. Kedir and Kouame (2022) used a probit model to analyse FinScope consumer survey data in Burkina Faso in 2016 and Cameroon in 2017 and found that FinTech influences women's entrepreneurship. The authors used women's business ownership or self-employment to measure entrepreneurship. The study limited the measure of FinTech development to using mobile money only. Abdeldayem and Aldulaimi (2021) established that crowdfunding platforms increase entrepreneurial finance in seven Middle East countries.

3.3 Digital finance and entrepreneurship

Several empirical studies examine the impact of digital finance for SMEs on entrepreneurship. However, these studies are concentrated in a single country, China. Wu and Wu (2023) examined the China Household Finance Survey (CHFS) data for 2017, 2019 and 2021 using FE, IV-Probit and IV-2SLS. The authors measured household entrepreneurship by a dummy variable of whether a family is self-employed or running a business, and digital finance measured by the dummy variable of whether the family uses digital payments, digital credit and digital money management. The authors found that digital finance promotes household entrepreneurship by enhancing entrepreneurial behaviour and alleviating financing constraints. Mao *et al.* (2023), Hu *et al.* (2023) and Ding *et al.* (2023) obtained similar results using CHFS data and the digital finance index from Peking University. In contrast, Li *et al.* (2022a) found that digital finance negatively and significantly impacts migrants' entrepreneurship by analysing the China Migrants Dynamic Survey data using logit models. These studies limited their analysis to self-employment and family entrepreneurship in China.

Gao *et al.* (2022) used the digital finance index from Peking University to measure digital finance and the number of new enterprise registrations to measure entrepreneurship in 284 Chinese districts from 2011 to 2019. The authors used FE and IV models for analysis and revealed that digital finance significantly promotes entrepreneurship by usage depth, coverage breadth and digitalisation level. Zhang and Pang (2023) found the same results that digital finance promotes urban entrepreneurship (sum of new private enterprises) and household entrepreneurship (new self-employed households) in China. Sun and You (2023) used the China Regional Innovation and Entrepreneurship Index data to examine the impact of digital finance on innovation and entrepreneurial activities in 41 districts from 2011 to 2020. The author conducted their analysis using multiple regression methods and established that digital finance significantly increases innovation and entrepreneurial activities in Chinese districts.

3.4 Institutional quality and FinTech developments

The last strand of literature explores the moderating effect of institutional qualities. This strand of literature is very limited. Haddad and Hornuf (2019) examined data from 5,588 FinTech start-ups from 55 countries from 2006 to 2014. Their analysis revealed that the strength of legal rights and regulations significantly impacts the formation of FinTech start-ups. Kowalewski *et al.* (2022) analysed the FinTech credit market growth data from 94 countries from 2013 to 2019. They found that institutional qualities (political stability, control of corruption, rule of law, contract enforcement and insolvency framework) influence the development of the FinTech credit market. Cornelli *et al.* (2023) obtained similar results that institutional attributes (investor protection disclosure, efficient judicial systems and ease of starting a new business) significantly impact FinTech developments and digital finance.

3.5 The existing gap in the reviewed literature

Previous empirical studies on FinTech development, digital finance to SMEs and entrepreneurship are comprehensive but have some limitations. First, most are limited to a country, case study, platform or specific locality. The reviewed studies offer robust empirical evidence only from China. Thus, extending the empirical analysis to developing economies, particularly Africa, will have valuable implications. Second, most of the reviewed empirical studies on digital finance analyse household entrepreneurship using "self-employed workers", limited to sole proprietorships, partnerships, cooperatives and contributing family workers. This paper uses a different measure of entrepreneurship, "new business density", which significantly impacts job creation in Africa (Eid, 2006; Malchow-Moller *et al.*, 2011; Malfense Fierro *et al.*, 2018). Third, almost no studies in Africa address this subject with a broad scheme of digital finance, except a few on mobile money. Finally, the reviewed studies use the mean estimation methods and do not explain the heterogeneity of the relationships between the dependent and explanatory variables. This leaves some insights into the relationships unknown. This paper bridges the gap by analysing the following:

- Cross-country data and focusing on 47 African countries where studies are limited.
- Data from the CCAF database that comprises different alternative financing schemes and FinTech companies. This paper is one of the first studies in Africa using the number of FinTech companies, which is a closer measure of FinTech development.
- Entrepreneurship data is based on "new business density", which has a broader impact on job creation than the "self-employed workers" proxy.
- The moderating effect of institutional quality as regulations on FinTech are considered essential for stability and innovation.
- Heterogeneous effects at various conditional quantiles distribution of the FinTech developments on digital finance and entrepreneurship.

4. Methodology

4.1 Data

To assess the linkages between the rise of FinTech companies, digital finance to SMEs and entrepreneurship, we use yearly data from 47 out of 54 countries in Africa over the period 2013–2020 from three different sources: the number of FinTech companies and the volume of digital finance to SMEs were obtained from CCAF's Global Alternative Finance Database; macroeconomic control variables and new business density were obtained from the World Development Indicators (WDI); and institutional quality variables were obtained from the World Governance Indicators (WGI). The seven African countries excluded in this study because of the unavailability of complete data are Djibouti, Eritrea, Ethiopia, Libya, São Tomé and Principe, Somalia and South Sudan.

The first dependent variable is digital finance to SMEs (DFS_{it}), which is the actual volume of transactions channelled to SMEs in US$ through digital lending and digital capital-raising activities per country per year. This includes digital financing services such as P2P business lending, crowd-lending, crowd-investing, crowdfunding (reward-based) and others, as recorded by CCAF. We take a logarithmic transformation of DFS values for the analysis. Other authors used different measures of digital finance, such as the digital finance index [6] from the Digital Finance Research Centre of Peking University (Yao and Yang,

2022), digital payment (Lin *et al.*, 2022), FinTech lending based on different platforms (Chen *et al.*, 2022) and mobile money (Lorenz and Pommet, 2021).

The second dependent variable is entrepreneurship (ENT_{it}). Previous studies use different proxies to measure entrepreneurship: new business density (the number of newly registered corporations as a limited liability in the calendar year per 1,000 people aged 15–64 years) (Dutta and Meierrieks, 2021); the number of patent or trademark applications per year (Dutta and Meierrieks, 2021; Yue *et al.*, 2023); new company formation rate (Chen, 2014; Malchow-Moller *et al.*, 2011); the number of self-employed workers (employees working with one or a few partners or in cooperatives on their account) (Malchow-Moller *et al.*, 2011); and newly registered entities for value-added tax (Malchow-Moller *et al.*, 2011). This paper uses "new business density" from WDI as a proxy of entrepreneurship, consistent with Dutta and Meierrieks (2021). This proxy has a vast impact on job creation.

The primary explanatory variable is FinTech developments ($FINTECH_{it}$), proxied by the number of FinTech companies. Empirical studies use different measures and proxies for FinTech, such as the digital inclusive financial index from the Digital Finance Research Centre of Peking University (Chen and Yoon, 2022; Xie and Liu, 2022), internet, mobile phone and broadband penetration (Hodula, 2022; Sheng, 2021), the number of FinTech companies (Huang, 2022), FinTech applications and services (Zhang *et al.*, 2022) and digital lending platforms (Chen *et al.*, 2022). Based on data availability in most African countries, we use the number of FinTech companies operating in each country as the proxy of FinTech developments from the CCAF database [7].

GDP per capita ($GDPG_{it}$), trade openness ($TRADE_{it}$) and inflation (INF_{it}) are used in this study as macroeconomic control variables. The institutional quality index ($INST_{it}$) is a moderating variable constructed using principal component analysis (PCA) [8] from WGI indicators, which are political stability, control of corruption, voice and accountability, government effectiveness, regulatory quality and the rule of law.

4.2 Model and estimation methods

Based on Sheng (2021) and Dutta and Meierrieks (2021), we define the following estimation equations and sub-equations with the mediating effects of institutional quality:

$$DFS_{it} = \beta_0 + \beta_1 FINTECH_{it} + \beta_2 CO_{it} + \mu_{it} \tag{1}$$

$$DFS_{it} = \beta_0 + \beta_1 FINTECH_{it} + \beta_2 INST_{it} + \beta_3 CO_{it} + \mu_{it} \tag{2}$$

$$DFS_{it} = \beta_0 + \beta_1 FINTECH_{it} + \beta_2 FINTECH_{it} \times INST_{it} + \beta_3 INST_{it} + \beta_4 CO_{it} + \mu_{it} \tag{3}$$

$$ENT_{it} = \beta_0 + \beta_1 FINTECH_{it} + \beta_2 CO_{it} + \mu_{it} \tag{4}$$

$$ENT_{it} = \beta_0 + \beta_1 FINTECH_{it} + \beta_2 INST_{it} + \beta_3 CO_{it} + \mu_{it} \tag{5}$$

$$ENT_{it} = \beta_0 + \beta_1 FINTECH_{it} + \beta_2 FINTECH_{it} \times INST_{it} + \beta_3 INST_{it} + \beta_4 CO_{it} + \mu_{it} \tag{6}$$

$$ENT_{it} = \beta_0 + \beta_1 DFS_{it} + \beta_2 CO_{it} + \mu_{it} \tag{7}$$

$$ENT_{it} = \beta_0 + \beta_1 DFS_{it} + \beta_2 INST_{it} + \beta_3 CO_{it} + \mu_{it} \quad (8)$$

$$ENT_{it} = \beta_0 + \beta_1 DFS_{it} + \beta_2 DFS_{it} \times INST_{it} + \beta_3 INST_{it} + \beta_4 CO_{it} + \mu_{it} \quad (9)$$

where DFS_{it} represents digital finance to SMEs, $FINTECH_{it}$ is FinTech development, ENT_{it} is entrepreneurship, $INST_{it}$ is institutional quality, CO_{it} is a vector of macroeconomic control variables (GDP growth, trade openness and inflation), β and μ_{it} are parameters and error vectors' $i = 1 \ldots n$ is the number of countries and $t = 1 \ldots T$ is the number of years in the panel.

Unlike previous empirical studies on FinTech and SME financing, this paper goes beyond the mean estimation methods by applying quantile regression (Koenker and Bassett, 1978) to obtain an insightful characterisation of the relationships between our dependent variables (DFS_{it} and ENT_{it}) and independent variable ($FINTECH_{it}$) across the varying distribution of DFS_{it} and ENT_{it}. The conventional mean regression methods explain the average change on DFS_{it} and ENT_{it} due to change on $FINTECH_{it}$. This provides a good explanation of the relationships, but focusing only on the mean can limit the results when we are interested in knowing the heterogeneity of the relationships. Thus, the quantile regression model manages outliers and heterogeneous effects of $FINTECH_{it}$ by quantifying changes across the distribution of DFS_{it} and ENT_{it} using conditional medians measured in quantile differences (p quantile). The quantile regression is robust in estimating local effects across the distribution due to changes in the independent variables. However, it does not account for the unobserved heterogeneity of individual effects within the panel data. It, therefore, suffers from incidental parameter problems (Lancaster, 2000). However, the MMQR introduced by Machado and Santos Silva (2019) is an intuitive approach that identifies unobserved heterogeneous covariance effects and manages endogenous independent variables in panel data models. Besides dealing with heterogeneity and endogeneity problems, MMQR produces robust estimates in diverse conditions for asymmetric and nonlinear models (An *et al.*, 2021; Ike *et al.*, 2020). We follow the MMQR model by Machado and Santos Silva (2019) to estimate the conditional quantiles $Q_Y(p|X_{it})$ by combining estimates of the location and scale functions:

$$Y_{it} = \alpha_i + X_{it}^{'}\beta + \left(\delta_i + Z_{it}^{'}\gamma\right)U_{it} \quad (10)$$

where $P\left\{\delta_i + Z_{it}^{'}\gamma > 0\right\} = 1$ is the probability. The parameters to be estimated are defined as $(\alpha, \beta', \delta, \gamma')$. The discrete i fixed effects are defined as (α_i, δ_i), $i = 1, \ldots, n$. Z describes the k-vector of recognised components of X, which are distinguishable transformations with j specified by: $Z_j = Z_j(X) j = 1, 2, \ldots, k$. X_{it} and U_{it} are autonomously and evenly distributed across individuals i, through time t, and are orthogonal to X_{it}. This satisfies the moment criteria in Machado and Santos Silva (2019). Thus, equation (10) implies the following:

$$Q_Y(p|X_{it}) = (\alpha_i + \delta_i q(p)) + X_{it}^{'}\beta + Z_{it}^{'}\gamma q(p) \quad (11)$$

where X_{it} contains all explanatory and control variables, which in this study are $FINTECH_{it}$, $GDPG_{it}$, $TRADE_{it}$, INF_{it} and $INST_{it}$. $Q_Y(p|X_{it})$ is the quantile distribution of the dependent variables Y_{it}, which in this study are DFS_{it} and ENT_{it} conditional on location of explanatory variable X_{it}. $\alpha_i + \delta_i q(p)$ is the scale coefficient showing the p quantile fixed effects across individual i. Finally, $q(p)$ is pth quantile estimated through resolving the subsequent optimisation problem as:

$$Minimise_q \sum_i \sum_t \rho_p \left(R_{it} - Z_{it}^{'} \gamma q(p) \right) \tag{12}$$

where $\rho_p(A) = (p–1)\, AI\{A \leq 0\} + TAI\{A > 0\}$ indicates a check function.

Finally, we use the instrumental variable mean estimation method, a two-stage least-squares (2SLS) regression (Anderson and Hsiao, 1982), for robustness checks. We use the 2SLS for robustness check because it is considered to be a robust method that addresses the endogeneity problem; it is prevalent and commonly used in social science, management and economics studies; and it is flexible and easily used in different research designs (Anderson, 2018).

5. Results

5.1 Descriptive statistics and diagnostic results

Table 1 presents the descriptive statistics of all the variables considered in this paper. As of 2019, each African country had at least 200 FinTech companies offering services. As of August 2023, Kenya, Nigeria, South Africa, Uganda and Ghana were the top five countries with the highest number of FinTech firms serving in their financial markets. Kenya had the highest number, with 399 FinTech firms in the country in 2021. As for digital finance to SMEs, the countries that reached more than US$10m per single year are Kenya, Nigeria, South Africa, Uganda and Rwanda. Nigeria reached the highest of all countries in digital finance to SMEs, with US$35m in 2016. We use logarithmic transformation for the number of FinTech firms, the amount of SMEs' digital finance and the new business density for analysis.

Table 2 shows a strong correlation between FinTech developments and digital finance extended to SMEs. Figure 2 illustrates the trend of FinTech developments in Africa from 53 FinTech firms in 2010 to 578 in 2023.

Table 3 indicates the diagnostic results, which confirm the absence of multicollinearity, endogeneity and autocorrelation. The heteroscedasticity and normality tests confirm that the residuals are neither homogeneous nor normally distributed. Furthermore, the Hausman test confirmed fixed effects. Thus, MMQR with multiple fixed effects is a robust method for our data set, as discussed in Section 4.2.

5.2 Empirical results and discussions

5.2.1 FinTech developments and digital finance to small and medium-sized enterprises.

Tables 4 and 5 present the results of the heterogeneous effect of FinTech developments on digital finance to SMEs using MMQR without and with macroeconomic control variables.

Variables	Definition	Obs	Mean	SD	Min	Max
$FINTECH_{it}$	The logarithm of the number of FinTech firms	251	4.858	0.429	4.111	5.961
DFS_{it}	The logarithm of the amount of SMEs' digital finance	251	10.2	3	1.884	17.376
ENT_{it}	The logarithm of new business density	179	−0.524	1.551	−4.758	3
$INST_{it}$	Index of institutional qualities (using PCA)	251	0	2.16	−4.51	5.88
$GDPG_{it}$	GDP growth (%)	251	3.73	3.60	−20.60	20.72
$TRADE_{it}$	Trade openness (%)	251	70.27	29.85	16.35	220.24
INF_{it}	Inflation (%)	251	6.34	15.07	−2.89	226.91

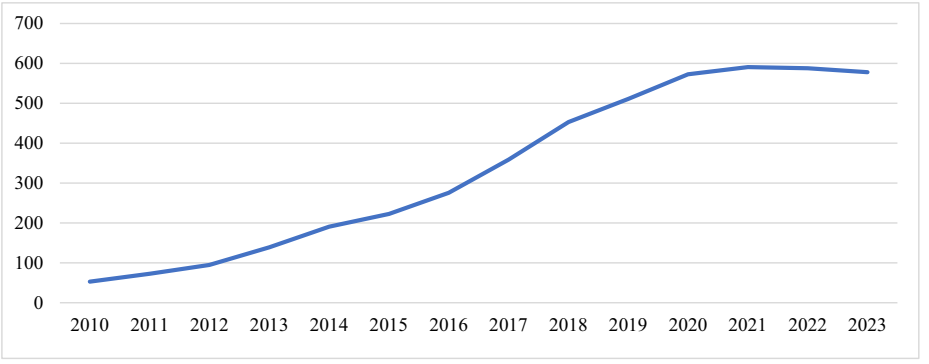
Table 1.
Descriptive statistics

Source: Authors' own work

No.	Variables	1	2	3	4	5	6	7
1	FinTech development	1						
2	Digital finance	0.260***	1					
3	Entrepreneurship	0.035	0.147*	1				
4	Institutional quality	−0.056	0.025	0.632***	1			
5	GDP Growth	−0.232**	−0.093	−0.235**	−0.038	1		
6	Trade Openness	−0.344***	−0.221**	0.240**	0.346***	−0.053	1	
7	Inflation	0.154*	0.031	−0.003	−0.170*	−0.293***	0.130	1

Notes: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$
Source: Authors' own work

Table 2.
Correlation matrix



Sources: Authors' own work; CCAF database

Figure 2.
The trend of active FinTech firms offering services in Africa from 2010 to 2023

Diagnostic test	Results	*p*-value	Results
Hausman test	chi2(5) = 25.70	0.0001	Fixed effect
Variance inflation factor (VIF)	Mean VIF = 1.16		There is no multicollinearity
VIF>10 or 1/VIF<0.1	1/VIF ranges between 0.785167 and 0.909075		
Durbin and Wu-Hausman tests	Durbin (score) chi2(1) = 0.004613	0.9459	There is no endogeneity
	Wu-Hausman F(1, 244) = 0.004484	0.9467	
Breusch-Pagan/ Cook-Weisberg test	chi2(1) = 7.17	0.0074	Presence of heteroscedasticity
Wooldridge test for autocorrelation in panel data	F (1, 37) = 0.754	0.3909	There is no autocorrelation (no serial correlation)
Skewness/Kurtosis tests for normality	Chi2 (2)	0.0000	The data is not normally distributed
Jarque-Bera normality test	Chi2 (2) = 1.8e+04	0.0000	

Source: Authors' own work

Table 3.
Diagnostic results

Table 4.
The effect of FinTech development on digital finance to SMEs without macroeconomic control variables

DFS_{it}	Location	Scale	MMQR Q(0.25)	Q(0.50)	Q(0.75)	2SLS
Panel A:						
$FINTECH_{it}$	3.111*** (0.420)	1.036*** (0.254)	2.297*** (0.486)	3.112*** (0.428)	4.075*** (0.479)	3.111*** (0.396)
Constant	−4.912** (1.990)	−2.915** (1.199)	−2.621 (2.268)	−4.915** (2.003)	−7.624*** (2.239)	−4.912** (1.933)
Panel B:						
$FINTECH_{it}$	3.097*** (0.420)	0.998*** (0.249)	2.317*** (0.485)	3.120*** (0.428)	4.049*** (0.475)	3.097*** (0.396)
$INST_{it}$	0.097 (0.076)	−0.043 (0.045)	0.130 (0.086)	0.096 (0.076)	0.056 (0.085)	0.097 (0.079)
Constant	−4.842** (1.984)	−2.719** (1.178)	−2.717 (2.263)	−4.907** (1.997)	−7.437*** (2.225)	−4.842** (1.932)
Panel C:						
$FINTECH_{it}$	3.121*** (0.418)	0.989*** (0.250)	2.336*** (0.478)	3.123*** (0.426)	4.021*** (0.470)	3.121*** (0.395)
$FINTECH_{it} \times INST_{it}$	0.331 (0.203)	−0.116 (0.121)	0.424* (0.229)	0.331 (0.203)	0.225 (0.226)	0.331* (0.193)
$INST_{it}$	−1.497 (0.952)	0.519 (0.569)	−1.909* (1.074)	−1.496 (0.953)	−1.025 (1.062)	−1.497 (0.932)
Constant	−4.970** (1.973)	−2.693** (1.179)	−2.833 (2.236)	−4.976** (1.987)	−7.421*** (2.207)	−4.970** (1.926)
Observations	251	251	251	251	251	251

Notes: Standard errors in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$
Source: Authors' own work

Table 5.
The effect of FinTech development on digital finance to SMEs with macroeconomic control variables

DFS_{it}	Location	Scale	MMQR Q(0.25)	Q(0.50)	Q(0.75)	2SLS
Panel D:						
$FINTECH_{it}$	2.596*** (0.445)	0.836*** (0.278)	1.883*** (0.524)	2.663*** (0.446)	3.391*** (0.499)	2.596*** (0.405)
$GDPG_{it}$	0.075 (0.052)	−0.033 (0.033)	0.103* (0.061)	0.072 (0.052)	0.043 (0.059)	0.075 (0.047)
$TRADE_{it}$	−0.027*** (0.005)	−0.009*** (0.003)	−0.020*** (0.006)	−0.028*** (0.005)	−0.035*** (0.006)	−0.027*** (0.006)
INF_{it}	0.027** (0.011)	−0.002 (0.007)	0.028** (0.012)	0.027** (0.011)	0.026** (0.012)	0.027** (0.011)
Constant	−0.954 (2.266)	−1.322 (1.417)	0.174 (2.652)	−1.061 (2.261)	−2.212 (2.544)	−0.954 (2.174)
Panel E:						
$FINTECH_{it}$	2.387*** (0.420)	0.813*** (0.241)	1.698*** (0.483)	2.412*** (0.426)	3.162*** (0.466)	2.387*** (0.402)
$INST_{it}$	0.264*** (0.076)	−0.095** (0.044)	0.345*** (0.087)	0.261*** (0.076)	0.173** (0.084)	0.264*** (0.079)
$GDPG_{it}$	0.067 (0.052)	−0.040 (0.030)	0.101* (0.059)	0.066 (0.052)	0.029 (0.057)	0.067 (0.046)
$TRADE_{it}$	−0.034*** (0.005)	−0.003 (0.003)	−0.031*** (0.006)	−0.034*** (0.005)	−0.037*** (0.006)	−0.034*** (0.006)
INF_{it}	0.033*** (0.010)	−0.005 (0.006)	0.038*** (0.012)	0.033*** (0.010)	0.028** (0.011)	0.033*** (0.011)
Constant	0.534 (2.187)	−1.543 (1.254)	1.842 (2.511)	0.485 (2.189)	−0.937 (2.406)	0.534 (2.176)
Panel F:						
$FINTECH_{it}$	2.425*** (0.417)	0.819*** (0.241)	1.756*** (0.476)	2.445*** (0.423)	3.196*** (0.463)	2.425*** (0.401)
$FINTECH_{it} \times INST_{it}$	0.339* (0.192)	−0.076 (0.111)	0.401* (0.218)	0.337* (0.192)	0.267 (0.212)	0.339* (0.183)
$INST_{it}$	−1.368 (0.897)	0.276 (0.519)	−1.593 (1.020)	−1.361 (0.897)	−1.108 (0.990)	−1.368 (0.884)
$GDPG_{it}$	0.0734 (0.051)	−0.042 (0.030)	0.107* (0.058)	0.072 (0.051)	0.0342 (0.057)	0.0734 (0.046)
$TRADE_{it}$	−0.033*** (0.005)	−0.004 (0.003)	−0.030*** (0.006)	−0.033*** (0.005)	−0.037*** (0.006)	−0.033*** (0.006)
INF_{it}	0.036*** (0.012)	−0.005 (0.006)	0.040*** (0.012)	0.036*** (0.011)	0.032*** (0.012)	0.036*** (0.011)
Constant	0.238 (2.160)	−1.533 (1.250)	1.489 (2.456)	0.199 (2.164)	−1.207 (2.387)	0.238 (2.171)
Observations	251	251	251	251	251	251

Notes: Standard errors in parentheses: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$
Source: Authors' own work

First, FinTech developments show a positive and strong relationship across all quantiles (low, medium and high) of digital finance for SMEs at the 1% significance level with or without control variables. These results confirm that the upsurge in digital finance delivered to SMEs is due to the rise in FinTech firms offering services in African countries.

The second and third columns of Tables 4 and 5 show the parameter estimations of location and scale functions, which maintain the linearity of the quantile and make it possible to contrast the MMQR results with other estimates obtained from different conventional linear methods. Second, location and scale parameters positively and significantly affect digital finance at the 1% significance level. This suggests that the rise of FinTech firms in African countries increases the average digital finance extended to SMEs at a magnitude of 1.036 but also increases the dispersion of observed digital finance to SMEs by 3.1. Table 5 shows similar results with different coefficients. The 2SLS results are the same as the 50th percentile and the location function results, consistent with previous empirical studies using mean estimation methods (Song *et al.*, 2023; Zhang *et al.*, 2022).

Third, the coefficients confirm the heterogeneous effect of FinTech development; they increase from 2.297 to 4.075 as the percentile of digital finance to SMEs increases from 0.25 to 0.75 quantiles. Table 5 shows similar findings with different coefficients. The MMQR results reveal more insights than previous studies (for example, Zhang *et al.*, 2022) that FinTech developments have a more substantial impact on high levels of digital finance for SMEs, almost double, compared to low levels. The practical implication of these heterogeneity results is that FinTech firms should strive to increase the variety of digital finance services and products available to SMEs, as a shift from one quantile to another increases the volume of digital finance for SMEs. As shown in descriptive statistics, the top five countries (Kenya, Nigeria, South Africa, Uganda and Ghana) with the highest number of FinTech firms serving in their financial markets are also the top five countries with the highest volumes of digital finance provided to SMEs. This implies that policymakers in countries with low levels of digital finance should create a conducive environment to attract more FinTech firms to increase the supply of digital finance for SMEs.

Finally, institutional quality has a strong positive effect on digital finance for SMEs when regressed as a control variable and macroeconomic control variables (see Table 5, Panel E). The coefficients of institutional quality decline from 0.345 to 0.173 as the percentile of digital finance to SMEs increases from the 25th to 75th percentiles. This shows that the moderating effect of institutional quality in digital finance is non-monotonic, with a higher impact on low levels than on high levels of digital finance. This is also evident in the interaction of FinTech and institutional quality, which is positive and significant at low and medium levels at 10% significance level (Table 4, Panel C and Table, Panel F). These heterogeneity findings suggest that policymakers should implement sound institutional qualities, which are more important at the initial stages of adopting FinTech and digital finance services for SMEs, to ensure their growth and stability.

5.2.2 FinTech developments and entrepreneurship. Tables 6 and 7, respectively, indicate the MMQR and 2SLS results of FinTech development impact on entrepreneurship with or without macroeconomic control variables. The results show that FinTech developments have an effect with opposite signs on the location and scale. The positive sign of the location function suggests that FinTech developments increase the dispersion of the observed entrepreneurship by 0.475 (Table 6, Panel A). The negative sign of the scale parameter implies that the marginal benefits from FinTech development diminish as entrepreneurship increases. In general, the MMQR results reveal that FinTech developments positively and significantly influence entrepreneurship, with the coefficients of FinTech developments declining as the percentiles of entrepreneurship increase. For example, when FinTech

Table 6. The effect of FinTech development on entrepreneurship without macroeconomic control variables

ENT_{it}	Location	Scale	MMQR Q(0.25)	Q(0.50)	Q(0.75)	2SLS
Panel A:						
$FINTECH_{it}$	0.475* (0.264)	−0.345** (0.167)	0.722** (0.286)	0.495* (0.264)	0.222 (0.298)	0.475* (0.265)
Constant	−2.839** (1.322)	2.877*** (0.838)	−4.898*** (1.451)	−3.012** (1.326)	−0.736 (1.505)	−2.839** (1.296)
Panel B:						
$FINTECH_{it}$	0.570*** (0.196)	−0.128 (0.123)	0.678*** (0.209)	0.573*** (0.196)	0.476** (0.229)	0.570*** (0.196)
$INST_{it}$	0.482*** (0.038)	−0.0723*** (0.024)	0.544*** (0.040)	0.484*** (0.037)	0.429*** (0.046)	0.482*** (0.040)
Constant	−3.302*** (0.972)	1.487** (0.610)	−4.563*** (1.040)	−3.342*** (0.968)	−2.213* (1.159)	−3.302*** (0.962)
Panel C:						
$FINTECH_{it}$	0.567*** (0.191)	−0.119 (0.120)	0.669*** (0.204)	0.570*** (0.190)	0.478** (0.223)	0.567*** (0.198)
$FINTECH_{it} \times INST_{it}$	−0.012 (0.091)	0.035 (0.057)	−0.042 (0.097)	−0.013 (0.090)	0.014 (0.105)	−0.012 (0.097)
$INST_{it}$	0.538 (0.440)	−0.240 (0.276)	0.745 (0.470)	0.545 (0.438)	0.359 (0.514)	0.538 (0.467)
Constant	−3.290*** (0.947)	1.445** (0.595)	−4.530*** (1.018)	−3.332*** (0.942)	−2.214* (1.134)	−3.290*** (0.970)
Observations	179	179	179	179	179	179

Notes: Standard errors in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$
Source: Authors' own work

Table 7.
The effect of FinTech development on entrepreneurship with macroeconomic variables

ENT_{it}	Location	Scale	MMQR Q(0.25)	Q(0.50)	Q(0.75)	2SLS
Panel D:						
$FINTECH_{it}$	0.706** (0.292)	−0.287 (0.180)	0.935*** (0.348)	0.695** (0.291)	0.457 (0.308)	0.706** (0.284)
$GDPG_{it}$	−0.059 (0.050)	−0.064** (0.031)	−0.008 (0.060)	−0.062 (0.050)	−0.115** (0.053)	−0.059* (0.033)
$TRADE_{it}$	0.013*** (0.005)	0.004 (0.003)	0.010* (0.006)	0.013*** (0.005)	0.017*** (0.005)	0.013*** (0.004)
INF_{it}	−0.008 (0.012)	0.001 (0.007)	−0.009 (0.014)	−0.008 (0.012)	−0.008 (0.013)	−0.008 (0.007)
Constant	−4.610*** (1.704)	2.517** (1.048)	−6.612*** (2.042)	−4.514*** (1.700)	−2.427 (1.811)	−4.610*** (1.545)
Panel E:						
$FINTECH_{it}$	0.408 (0.268)	−0.336* (0.181)	0.692** (0.271)	0.398 (0.268)	0.153 (0.331)	0.408* (0.218)
$INST_{it}$	0.496*** (0.049)	−0.069** (0.033)	0.554*** (0.050)	0.494*** (0.049)	0.444*** (0.061)	0.496*** (0.044)
$GDPG_{it}$	−0.041 (0.050)	−0.063* (0.034)	0.012 (0.051)	−0.042 (0.050)	−0.088 (0.062)	−0.041 (0.025)
$TRADE_{it}$	−0.001 (0.003)	−0.002 (0.002)	0.0002 (0.003)	−0.002 (0.003)	−0.003 (0.004)	−0.001 (0.003)
INF_{it}	0.008 (0.009)	−0.001 (0.006)	0.009 (0.009)	0.008 (0.009)	0.007 (0.011)	0.008 (0.005)
Constant	−2.301 (1.553)	2.872*** (1.050)	−4.728*** (1.586)	−2.220 (1.553)	−0.120 (1.917)	−2.301* (1.191)
Panel F:						
$FINTECH_{it}$	0.411 (0.280)	−0.328 (0.201)	0.684*** (0.264)	0.411 (0.278)	0.159 (0.367)	0.411* (0.220)
$FINTECH_{it} \times INST_{it}$	0.013 (0.116)	0.0305 (0.083)	−0.013 (0.109)	0.013 (0.116)	0.036 (0.154)	0.013 (0.098)
$INST_{it}$	0.434 (0.564)	−0.214 (0.404)	0.613 (0.527)	0.434 (0.564)	0.270 (0.745)	0.434 (0.475)
$GDPG_{it}$	−0.040 (0.053)	−0.062 (0.038)	0.011 (0.050)	−0.040 (0.053)	−0.088 (0.069)	−0.040 (0.025)
$TRADE_{it}$	−0.001 (0.002)	−0.002 (0.003)	0.0001 (0.003)	−0.001 (0.004)	−0.003 (0.005)	−0.001 (0.003)
INF_{it}	0.008 (0.009)	−0.001 (0.007)	0.009 (0.009)	0.008 (0.009)	0.008 (0.012)	0.008 (0.006)
Constant	−2.321 (1.630)	2.826** (1.168)	−4.677*** (1.553)	−2.320 (1.613)	−0.150 (2.116)	−2.321* (1.205)
Observations	179	179	179	179	179	179

Notes: Standard errors in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$
Source: Authors' own work

development is regressed with institution quality as a control variable (Table 6, Panel B), a 1% increase in FinTech development increases entrepreneurship by 0.678% at the 25th percentile, 0.573% at the 50th percentile and 0.476% at the 75th percentile. Table 7, Panel D, shows similar results when regressed with macroeconomic control variables. FinTech developments significantly and positively impact entrepreneurship more at the lower than the higher level. These findings suggest that the rise of FinTech firms in Africa strongly affects the nascent stages of entrepreneurship. But, its effect diminishes as the growth of entrepreneurship increases to maturity level. Given that entrepreneurship is still at the nascent stage in most African countries, promoting FinTech development will help to stimulate entrepreneurial activities. The findings of 2SLS (the mean estimation) are similar to MMQR results for the location function and 50th percentile, which are aligned with previous empirical studies (Kedir and Kouame, 2022; Yue *et al.*, 2023) using the mean estimation methods. This confirms the robustness of the MMQR results.

Finally, the institutional quality index has a significant and positive heterogeneous effect on entrepreneurship when regressed as a control variable with or without macroeconomic control variables. The coefficients of institutional quality diminish from 0.544 to 0.429 as the percentile of entrepreneurship increases. These heterogeneity results imply that sound institutional qualities are essential for the development of both FinTech entrepreneurship, as they create confidence for entrepreneurs to use digital finance.

5.2.3 Digital finance and entrepreneurship. Tables 8 and 9 report the results of the influence of digital finance extended to SMEs on entrepreneurship using MMQR without and with macroeconomic control variables. First, the scale parameter in Tables 8 and 9 has a negative but insignificant effect. In contrast, the location model has a positive and significant impact on the dispersion of entrepreneurship when regressed with institutional quality as a control variable (Table 8, Panel B) and with macroeconomic control variables (Table 9, Panel D). The findings from 2SLS are similar to the location function and the 50th percentile and consistent with previous studies on entrepreneurship (Li *et al.*, 2022b; Mao *et al.*, 2023; Wu and Wu, 2023). This confirms the robustness of the MMQR results.

Second, digital finance delivered to SMEs has a positive and more substantial effect at lower levels of entrepreneurship than at higher levels, with the coefficients decreasing from 0.088 at the 25th percentile to 0.066 at the 75th percentile (Table 8, Panels B and C). Similar results are obtained when regressed with macroeconomic factors (Table 9, Panel D). These findings reveal more information than the previous studies (Li *et al.*, 2022b; Mao *et al.*, 2023; Wu and Wu, 2023) that the reliance on digital financing is more substantial at the nascent and transitional development stages of entrepreneurship but reasonably declines as entrepreneurship increases and becomes mature. Practically, this means that digital finance for SMEs helps entrepreneurs at the nascent stage to build their assets and credit history, giving them more comprehensive access to finance from financial institutions at the maturity level. The practical implication of these heterogeneous results is that entrepreneurs and SMEs at the nascent stage would benefit from the intensive promotion of digital finance services in African countries. Hence, policymakers supporting entrepreneurs and SMEs that often face challenges in accessing traditional financing at the nascent stage should promote digital finance services in their economies.

Finally, the institutional quality index significantly and positively affects entrepreneurship when regressed as a control variable without macroeconomic control variables. The results further show that institutional qualities have a moderating effect on digital finance extended to SMEs, with a diminishing coefficient from 0.554 at the 25th percentile to 0.420 at the 75th percentile (Table 8, Panel B). However, the institutional quality index has an insignificant moderating effect when regressed with macroeconomic variables (Table 9). These

Table 8.
The effect of digital finance for SMEs on entrepreneurship without macroeconomic variables

ENT_{it}	MMQR					2SLS
	Location	Scale	Q(0.25)	Q(0.50)	Q(0.75)	
Panel A:						
DFS_{it}	0.050 (0.039)	−0.038 (0.025)	0.078* (0.043)	0.051 (0.039)	0.022 (0.044)	0.050 (0.040)
Constant	−1.051** (0.446)	1.595*** (0.281)	−2.239*** (0.499)	−1.099** (0.456)	0.142 (0.519)	−1.051** (0.433)
Panel B:						
DFS_{it}	0.077*** (0.029)	−0.013 (0.018)	0.088*** (0.031)	0.078*** (0.029)	0.066** (0.033)	0.077*** (0.029)
$INST_{it}$	0.486*** (0.038)	−0.080*** (0.023)	0.554*** (0.042)	0.489*** (0.038)	0.420*** (0.046)	0.486*** (0.040)
Constant	−1.335*** (0.319)	1.015*** (0.196)	−2.210*** (0.362)	−1.372*** (0.322)	−0.500 (0.396)	−1.335*** (0.322)
Panel C:						
DFS_{it}	0.079*** (0.029)	−0.016 (0.018)	0.092*** (0.031)	0.080*** (0.029)	0.066* (0.034)	0.078*** (0.030)
$DFS_{it} \times INST_{it}$	−0.066 (0.098)	0.064 (0.061)	−0.117 (0.105)	−0.069 (0.097)	−0.014 (0.115)	−0.006 (0.014)
$INST_{it}$	0.805* (0.473)	−0.388 (0.296)	1.113** (0.509)	0.821* (0.472)	0.484 (0.558)	0.549*** (0.145)
Constant	−1.357*** (0.329)	1.036*** (0.206)	−2.182*** (0.366)	−1.401*** (0.330)	−0.500 (0.414)	−1.348*** (0.324)
Observations	179	179	179	179	179	179

Notes: Standard errors in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$
Source: Authors' own work

Table 9. The effect of digital finance on SMEs on entrepreneurship with macroeconomic variables

			MMQR			
ENT_{it}	Location	Scale	Q(0.25)	Q(0.50)	Q(0.75)	2SLS
Panel D:						
DFS_{it}	0.115*** (0.042)	0.007 (0.026)	0.109** (0.051)	0.115*** (0.041)	0.121*** (0.043)	0.115*** (0.043)
$GDPG_{it}$	−0.073 (0.047)	−0.060** (0.030)	−0.025 (0.058)	−0.078* (0.046)	−0.127*** (0.049)	−0.073** (0.032)
$TRADE_{it}$	0.015*** (0.005)	0.006* (0.003)	0.010 (0.006)	0.015*** (0.005)	0.020*** (0.005)	0.015*** (0.004)
INF_{it}	−0.009 (0.012)	−0.001 (0.008)	−0.009 (0.015)	−0.009 (0.012)	−0.010 (0.013)	−0.009 (0.007)
Constant	−2.410*** (0.720)	0.847* (0.456)	−3.087*** (0.884)	−2.342*** (0.715)	−1.643** (0.746)	−2.410*** (0.665)
Panel E:						
DFS_{it}	0.063 (0.708)	−0.024 (0.717)	0.083 (1.291)	0.063 (0.695)	0.045 (0.174)	0.063* (0.033)
$INST_{it}$	0.495 (0.951)	−0.079 (0.964)	0.561 (1.671)	0.494 (0.899)	0.434* (0.226)	0.495*** (0.044)
$GDPG_{it}$	−0.049 (0.871)	−0.058 (0.882)	−0.001 (1.545)	−0.049 (0.831)	−0.093 (0.209)	−0.049** (0.025)
$TRADE_{it}$	−0.001 (0.070)	−0.001 (0.070)	−0.0002 (0.128)	−0.001 (0.069)	−0.001 (0.017)	−0.001 (0.003)
INF_{it}	0.007 (0.167)	−0.002 (0.169)	0.009 (0.307)	0.007 (0.165)	0.006 (0.041)	0.007 (0.005)
Constant	−0.994 (12.00)	1.384 (12.16)	−2.143 (20.83)	−0.979 (11.21)	0.061 (2.817)	−0.994* (0.521)
Panel F:						
DFS_{it}	0.065 (0.042)	−0.028 (0.032)	0.087* (0.045)	0.066 (0.042)	0.044 (0.052)	0.063* (0.033)
$DFS_{it} \times INST_{it}$	−0.031 (0.133)	0.073 (0.100)	−0.091 (0.142)	−0.034 (0.132)	0.024 (0.167)	−0.003 (0.014)
$INST_{it}$	0.644 (0.639)	−0.428 (0.481)	0.999 (0.680)	0.659 (0.634)	0.316 (0.798)	0.525*** (0.149)
$GDPG_{it}$	−0.049 (0.052)	−0.057 (0.039)	−0.001 (0.055)	−0.047 (0.051)	−0.093 (0.064)	−0.049** (0.025)
$TRADE_{it}$	−0.001 (0.004)	−0.001 (0.003)	−0.0002 (0.004)	−0.001 (0.004)	−0.001 (0.005)	−0.001 (0.004)
INF_{it}	0.007 (0.012)	−0.001 (0.008)	0.008 (0.011)	0.007 (0.011)	0.006 (0.013)	0.007 (0.006)
Constant	−1.005 (0.704)	1.415*** (0.530)	−2.178*** (0.751)	−1.054 (0.691)	0.077 (0.864)	−0.986* (0.524)
Observations	179	179	179	179	179	179

Notes: Standard errors in parentheses: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$
Source: Authors' own work

heterogeneity results suggest that sound institutional qualities are necessary for nascent entrepreneurs to have confidence in adopting digital finance.

6. Conclusion and implications

This paper examined the heterogeneous:

- effect of FinTech developments on digital finance extended to SMEs;
- impact of FinTech developments on entrepreneurship in Africa;
- influence of digital finance delivered to SMEs on entrepreneurship; and
- moderating effect of institutional quality on the above cases.

We used the number of FinTech companies offering services in African countries as the proxy for FinTech development and the amount of digital finance extended to SMEs in African countries from the CCAF database from 2013 to 2020. Our heterogeneity analysis revealed the following insightful results.

First, FinTech developments have a positive and more potent impact on high levels of digital finance for SMEs, almost double compared to low levels. Thus, in answer to our first research question, the results confirm the heterogeneous effect of FinTech development as they increase from 2.297 to 4.075 when the percentile of digital finance for SMEs increases from 0.25 to 0.75 quantiles. Second, FinTech developments have positive and considerable effects in countries where entrepreneurship is at the initial stages of development, but its effect diminishes as the growth of entrepreneurship increases. A 1% increase in FinTech development increases entrepreneurship by 0.678% at the 25th percentile, 0.573% at the 50th percentile and 0.476% at the 75th percentile. Thus, as entrepreneurship develops, the marginal benefits from FinTech development reduce relative to a lower level of entrepreneurship. Third, digital finance for SMEs has a positive and more substantial influence at entrepreneurship's initial and transitional development stages but reasonably declines as entrepreneurship matures. This answers our third research question, as the coefficients decrease from 0.088 at the 25th percentile to 0.066 at the 75th percentile of entrepreneurship development. Finally, institutional quality has a substantial positive moderating effect on FinTech developments, the amount of digital finance for SMEs and entrepreneurship when used as a control rather than an interaction variable. The moderating effect is more pronounced at the nascent stage of entrepreneurship development, which answers our fourth research question. We suggest the following practical and policy recommendations based on these heterogeneity findings.

First, FinTech firms should strive to increase the variety of digital finance services and products available to SMEs in Africa, as a shift from one to another quantile increases the volume of digital finance for SMEs. This is evident in countries such as Kenya, Nigeria, South Africa, Uganda and Ghana, which have the highest number of FinTech firms operating in their economies, making them the top five countries with the highest volumes of digital finance for SMEs. Second, helping entrepreneurs and SMEs at the nascent stage of development use FinTech services will widen their financing options and increase their entrepreneurial activities. Easy access to digital finance helps nascent entrepreneurs and SMEs build their creditworthiness.

Consequently, policymakers and development partners, particularly in countries with low levels of digital finance, should create a conducive environment, including sound institutional qualities, to attract more FinTech firms and increase the supply of digital finance for SMEs. Implementing policies that promote FinTech development and digital finance services will stimulate alternative financing options for nascent African entrepreneurs and SMEs, who often face challenges in accessing traditional financing. This includes cutting down taxes and levies on digital transactions to make the services

affordable. In addition, policymakers and development partners should implement sound regulations to encourage the adoption of digital finance. Sound regulation will also mitigate the risks associated with FinTech development and adoption of digital finance.

This study contributes to the existing literature by revealing insightful empirical findings from heterogeneity analysis using the novel MMQR method across varying development stages of digital finance (low, medium and high) and entrepreneurship (nascent, transitional and mature). However, it has some limitations. First, we measure FinTech development using the number of FinTech firms operating in an economy. It will be interesting for future studies to use a richer measure of FinTech development that accounts for digitalisation level, breadth of coverage and usage when data becomes available. Second, our empirical analysis is based on macro-level data. Therefore, future studies may explore firm-level data, including experimental research using innovation hubs, incubators and accelerators. This could help explain how SMEs, entrepreneurs and start-ups accessing digital finance perform over time. Finally, future studies may focus on the effect of digital finance on SMEs' growth, job creation and overall impact on inclusive economic growth.

Notes

1. The Financial Stability Board (FSB) defines FinTech as "technologically enabled financial innovation that could result in new business models, applications, processes, or products with an associated material effect on financial markets and institutions and the provision of financial services" (Bank for International Settlements, 2018, p. 8).
2. Digital finance refers to a wide range of digital lending and capital-raising options, such as marketplace (peer-to-peer) lending (P2P), crowd-funding, crowd-lending, crowd-investing, ICOs, blockchain-based securities and lending systems, mobile money and credit schemes, big data and analytics-based financing and artificial intelligence (AI)-based credit schemes.
3. The Cambridge Centre for Alternative Finance (CCAF) at the University of Cambridge Judge Business School conducts survey and research on "the development of FinTech markets and industry verticals, FinTech regulation and regulatory innovation, supervisory technology and its application in financial authorities, digital assets and digital money". CCAF has a database of FinTech developments and digital activities such as digital lending and capital-raising options, etc.
4. Big data is described as information assets with five "*V*" dimensions: *Volume* (high volume of data sets), *Velocity* (speed of collecting and processing data), *Variety* (variety of data sets), *Veracity* (quality of data) and *Value* (data usefulness) (Onay and Öztürk, 2018).
5. The entropy method is a "mathematical method used to judge the dispersion degree of an index. The greater the degree of dispersion, the greater the impact of the index on the comprehensive evaluation" (Xiao *et al.*, 2022).
6. This digital inclusive financial index is calculated using data from Yu'ebao and Alipay with three dimensions: coverage (account coverage or number of users), usability (payment transactions, money fund business, credit services, insurance services, investment portfolio, and credit operations), and digitization (mobility, affordability and credibility) (Guo *et al.*, 2019). Alipay, owned by the leading e-commerce giant – Alibaba Group, is China's largest third-party online mobile payment system. Yu'ebao, a subsidiary of Alibaba's Ant Financial Services Group, is China's largest money market fund used by more than 400 million individual investors.
7. CCAF database is an emergent database with rich cross-section data of FinTech companies and digital finance which include digital lending, digital payments, enterprise technology provisioning, digital capital raising, crypto-asset exchange, wealth-tech, insur-tech, digital banks, digital custody, alternative credit analytics, digital savings and consensus services. The data sets start from 2010 onwards.

8. We estimated the eigenvalues of the covariance matrix to obtain the eigenvectors (the principal components). Then we obtained significant scores (principal components) based on Kaiser-rule of eigenvalue equal to or greater than one. Based on this rule, only one component was selected.

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