

Title

FinTech, financial inclusion, and different dimensions of inequality: Channels and Evidence

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Abstract

This study investigates the relationship between FinTech, financial inclusion, and different dimensions of inequality, (gender, income, and carbon) for a panel of 113 nations using the Global Findex waves of survey data from 2011, 2014, 2017, and 2021. The study employs structural equation modelling to simulate both the direct and indirect effects. The key findings include (i) FinTech significantly increases income inequality and reduces gender inequality (through financial inclusion). (ii) FinTech promotes financial inclusion. (iii) Financial inclusion reduces all dimensions of inequality. (iv) Regulatory quality, education, and access to credit reduce different dimensions of inequality through financial inclusion. These results add to a modest but growing body of work on the role of FinTech and financial inclusion in fostering better resource distribution and inclusive development across countries. Moreover, this is the first study to investigate different dimensions of inequality and model inter-relationships. The study provides preliminary evidence of the varying distributional effects of FinTech and financial inclusion on different dimensions of inequality.

Track

Financial Management Track (Financial Technology (FinTech), Financial Intermediation)

Word Count

6970 words

1. Introduction

There has been a lot of attention on the nexus between different elements of finance and various dimensions of inequality (De Haan and Jan-Egbert (2017), Meniago and Asongu (2018), Altunbas and Thornton (2019), Ouechtati (2020). A key tenet of such studies is to highlight the essential role of financial institutions and markets in the better allocation of resources, eventually leading to economic growth and development (Murinde 2012). Financial access, in particular, allows the poor to gain access to income-generating opportunities, which contribute to the formation of investment, employment, and opportunities (Basu and Mallik, 2007).

An increasing volume of research investigates the relationship between financial inclusion and inequality. Strong evidence in the literature indicates that the introduction of commercial banks and better financial access for the poor helps reduce inequality and improve their well-being (Allen et al., 2013; Neaime, et. al., 2019). The UN 2030 Agenda for Sustainable Development also acknowledges that financial inclusion is essential to meeting the Sustainable Development Goals (SDGs) and reducing inequality (Klapper, et.al., 2016).

More recently, there appears to be a lot of optimism and aspiration that recent advancements in financial technology (FinTech) will present opportunities to remove obstacles to financial inclusion and that financial institutions are providing products and services that are more closely matched to customers' needs at a lower price (Arner, et. al., 2020; Boot, et. al., 2020; Philippon, 2020; Thakor, 2020). Mobile financial services are believed to have the greatest potential to bring the remaining underbanked into the formal financial system and, ultimately, achieve more equitable growth (GPFI 2016; Demirguc-Kunt, et. al., 2018). FinTech has the potential to significantly alter how businesses mobilise resources from their environment and communicate with resource suppliers (Cumming, et. al., 2021).

Yet the World Bank estimates that 2 billion adults globally still do not have access to formal financial services, despite the tremendous progress that has been made in this area in recent years. High costs, distance, and documentation requirements are frequently cited as justifications for not having or using a financial institution account (Demirguc-Kunt, et. al., 2018). Many anticipated that FinTech would encourage financial inclusion and assist disadvantaged populations (Demirguc-Kunt, et. al., 2018; Breza, et. al., 2020). In fact, according to Sheng, et. al., (2021), the current COVID-19 pandemic has increased the growth of digitalization, making it even more influential in the process of mobilising resources. Nevertheless, despite the abundance of research on the subject, very few have offered clear empirical evidence of how FinTech affects financial inclusion and how this can finally provide insight into the issue of inequality and the disparity in the allocation of resources. This is because quantifying FinTech is difficult since the scope and scale of its products vary widely. The difficulty has also been exacerbated by the fragmented and short time series data.

By examining the connections between FinTech, financial inclusion, and various dimensions of inequality across a broad panel of 113 nations using the Global Findex waves of survey data for 2011, 2014, 2017, and 2021, this research aims to rise to the challenge. Our paper is based on several key strands of literature. The first thread focuses on the nexus between financial inclusion and inequality (Beck, et al., 2007; Dabla-Norris, et. al., 2015; DeHaan and Sturm 2017; Park and Mercado, 2018). The second thread focuses on the connection between inequality and FinTech (Jaumotte, et.al., 2013; Asongu 2015; Dabla-Norris et al. 2015c; Richmond and Triplett 2018). The third key focuses on the FinTech-financial inclusion nexus (Sahay, et. al., 2020, Jack and Suri 2011; Mbiti and Weil 2011; Ghosh 2016; Gosavi 2018; Tchamyou, et.al., 2019; Morawczynski, 2009; Jack and Suri 2011; Mbiti and Weil 2011; Ouma, et.al., 2017). Lastly, the final thread discusses the key enablers of the process of resource

mobilisation (Demertzis, et. al., 2018; Kanga, et.al., 2019; Claessens, et. al., 2018; Manyika, et.al., 2016; Sharma 2016; Becker 2017; Gabor, 2019; Michael, 2019).

The paper aims to make significant contributions by integrating these strands of literature. First, we try to investigate how FinTech contributes to the increase or decrease of different dimensions of inequality. Second, we examine how financial inclusion is changing as a result of FinTech and establish the mediating role of financial inclusion in the relationship between FinTech and inequality. Third, we aim to understand how key enablers including regulatory quality, education, and financial deepening significantly influence the FinTech-financial inclusion-inequality relationship. In contrast to other empirical research on financial inclusion that mainly employed supply-side data (e.g. Hannig and Jansen, 2010; Beck et.al, 2008) we use demand-side data from the Global Findex database, the largest source of data available on how adults save, pay bills, borrow, and manage risk. The rest of the paper is organised as follows. The detailed literature is discussed in Section 2. Section 3 covers the research methodology. Section 4 discusses the results and findings, while Section 5 concludes and offers policy implications.

2. Review of literature

Financial inclusion refers to households and businesses' access to and use of formal financial services. Policymakers regard it as a means to enhance people's livelihoods, decrease poverty, and advance economic development (Sahay, et.al., 2015; Demirgüç-Kunt, & Singer, 2017). Financial inclusion can also be defined as having access to and using financial services that satisfy the needs of the user (Claessens & Rojas-Suarez, 2016; Allen, et.al., 2016). In recent years FinTech has helped improve financial intermediation by reducing cost and enhancing access (Philippon, et.al., 2019). Financial innovation, in the form of new delivery channels, products, and providers, has aided in pushing out the frontier of access to finance, increasing the bankable and banked population. The same financial innovation has dissolved the financial system's regulatory borders, with nonbanks, including telecom businesses and huge technologies, offering financial services and gradually expanding into the financial intermediation industry (Arner, et.al., 2020; Jagtiani, & Lemieux, 2017).

There was increased anticipation that proliferation of FinTech and financial inclusion tools will help reduce inequality. Inequality is a multidimensional notion. The present inequality literature focuses mainly on a single aspect of inequality. Piketty and Saez (2003) and Burkhauser et al. (2012) focus solely on income inequality. Those who study consumption inequality frequently relate the trend in consumption inequality to the trend in income inequality (Blundell et al., 2008; Attanasio and Pistaferri, 2014; Aguiar and Bils, 2015; Fisher et al., 2015; Meyer and Sullivan, 2016). Similarly, wealth inequality is frequently examined separately or in conjunction with income inequality (e.g., Wolff, 2014; Saez and Zucman, 2016). According to the World Inequality Report 2022, global wealth inequalities are even more pronounced than income inequalities. In contrast to the richest 10% of the world's population, who control 76% of it, the poorest half of the population owns only 2% of the world's wealth (Chancel, et.al., 2022). This demonstrates how national income tells us very little about the numerous characteristics of inequality that can be perpetuated by inequities (showing the presence of injustice, unfairness, and bias), which are frequently overlooked in much research (Morello-Frosch, et.al., 2011; Yearby, 2020; Pensiero, et.al., 2020, Tomasik, et.al., 2021). Despite this, most studies of inequality concentrate on a single dimension. We will get a deeper, broader, and more nuanced understanding of inequality by researching its multidimensional aspects.

Inequality and FinTech

By increasing access to opportunities and income, information and communication technology (particularly FinTech) can significantly contribute to the reduction of inequality (Aker and Mbiti, 2010). There is evidence from Asongu and Le Roux (2017) and Asongu and Odhiambo (2019) that greater mobile and internet penetration can lessen income inequality in African countries. Studies carried out in developing nations in Latin America and Africa confirm the growing benefits of technology, particularly FinTech, in enabling households to escape the vicious cycle of poverty and accumulate savings (Abor, et.al., 2018; Beuermann, et.al., 2012; Suri and Jack, 2016). Evidence from China demonstrates that FinTech narrows the income gap between rural and urban areas by encouraging rural entrepreneurship (Zhang, et. al., 2018; Ge, et.al., 2022). FinTech alters household financial practices and has an impact on career decisions. Evidence from India and Niger demonstrates that digitising government payments lowers administrative expenses and corruption, freeing up more money for social investment and reducing wealth inequality (Aker et al. 2011; Muralidharan, et. al., 2014). But studies also propose the cautious and planned implementation of FinTech, as in certain contexts it can exacerbate income inequality (Li and Li, 2021)

Physical constraints could be easily overcome by FinTech, allowing financial services to reach geographically isolated areas. The advantages of FinTech might be greater when viewed through the lens of gender. FinTech can make financial services more accessible and more widely used (Sahay, et al., 2020), more accurately assess the creditworthiness of traditionally underrepresented women (Loko and Yong, 2022), and make it easier for small enterprises owned by women to acquire finance (Morgan, 2022). Chen, et. al. (2021) and Gurner (2021) conclude that finance and technology penetration significantly stimulates female labour market participation. However, Asongu and Odhiambo (2019) emphasise that boosting ICT beyond certain baselines is necessary to alleviate inequality in order to increase female participation in the economy. However, some studies also highlight the challenges of rising gender divide perpetuated by FinTech (Anandhita and Ariansyah, 2018; Adeleke et al., 2021).

Evidence on the influence of FinTech on carbon inequality is very mixed. While some studies suggest that FinTech increases carbon emissions and disparity (Acheampong, 2019; Sadorsky, 2010; Abbasi and Riaz, 2016; Solarin, et. al., 2017; Kihombo et al., 2021). Other studies demonstrate that finance and related technology can reduce emissions and inequality (Tamazian, et. al., 2009; Ahmed et al., 2021; Sheraz, et. al., 2021; Odhiambo, et.al., 2020; Charfeddine and Khediri, 2016; Xing, et. al., 2017). Therefore, from the foregoing discussion on FinTech and inequality, the following hypothesis is derived:

H1: There is a significant relationship between FinTech and inequality

Financial inclusion and inequality

Numerous cross-national studies (Honohan 2007, Mookerjee and Kalipioni 2010, Hermes 2014, Sahay et al. 2015, Kim 2016, Aslan et al. 2017, Park and Mercado 2018, Turégano and Herrero 2018) have found a correlation between higher financial inclusion levels and lower income inequality. Studies using multiple key indicators of financial inclusion show that nations with less unequal income distribution typically have a more inclusive financial system (Kai and Hamori 2009; Lacalle-Calderon, et al., 2019). More financial inclusion seems to be linked to lower income inequality in the Middle East and North Africa (Neaime and Gaysset 2018), but not in certain regions of Asia (Park and Mercado, 2018), Sub-Saharan Africa (Tita and Aziakpono, 2017), or Latin America (Dabla-Norris, et. al., 2015). This suggests that while financial inclusion is likely to be associated with reduced income inequality, the nature of

financial institutions, markets, and instruments available, as well as the types of financial inclusion policies pursued, may have a different impact on this relationship.

Financial inclusion may be hampered by a persisting gender disparity in FinTech adoption, according to Chen, et. al., (2021). Fintech goods that complement well-known services are more likely to be adopted by women. This shows that disparities in views toward technology and price sensitivity are closely related to the disparity in Fintech usage. Additionally, it was noted that women were substantially less likely to adopt new financial technology. In general, women are less likely than males to own bank accounts (Demirguc-Kunt, et. al., 2017), handle household finances (Guiso and Zaccaria, 2021), or invest in the stock market (Ke, 2020). While Fintech has helped most nations close gender inequalities in financial inclusion, Sahay, et. al., (2020) concluded that there is concern that this gender gap might expand in the post-COVID age. Evidence points to gender variations in attitudes and preferences toward new financial technology as the cause of the disparity in FinTech adoption. As these new FinTech products become more standardised and regulated over time, the gender gap may begin to close (Chen, et. al., 2021)

The effects of financial inclusion on carbon emissions and growing inequality have scarcely been studied (Usman, et. al., 2021). An Oxfam and the Stockholm Environment Institute (SEI) report suggests that between 1999 and 2015, the world's richest 1%'s consumption was responsible for twice as many carbon emissions as the combined emissions of the world's lowest half. In this period of enormous carbon disparity, the climate crisis intensified. Some studies have found that financial inclusion is increasing carbon emissions and inequity (Le, et. al., 2020; Lei, et. al., 2020; Zhao and Yang, 2020). While other studies show that financial inclusion can be an important tool in reducing carbon emissions (Renzhi and Baek, 2020; Zaidi and Hassan, 2021; Odhiambo et. al., 2020). Based on the foregoing discussion on financial inclusion and inequality the following hypotheses are derived.

H2a. There is a significant relationship between financial inclusion and inequality

H2b. There is a mediation effect of financial inclusion in the relationship between FinTech and inequality

FinTech and financial inclusion

Cross-border payments, peer-to-peer lending, and credit risk evaluations are just a few examples of the many different fintech products available today. Digital options include mobile money, mobile banking, marketplace lending, and digital payments and lending/credit (Sahay, et. al., 2020). Even where traditional financial inclusion was stagnating or declining, digital financial inclusion increased between 2014 and 2021 in several countries according to the latest Global Findex Survey results.

The majority of studies have discovered that FinTech and digitalization are key forces toward financial inclusion (Jack and Suri 2011; Mbiti and Weil 2011; Ghosh 2016; Gosavi 2018; Tchamyou, et.al., 2019). Financial inclusion has a strong positive relationship with FinTech in the form of mobile phone use and mobile money use (Andrianaivo and Kpodar 2012; Ghosh 2016;). Households with mobile money accounts are more likely to have bank accounts, send and receive money more regularly, and save more money (Morawczynski, 2009; Jack and Suri 2011; Mbiti and Weil 2011; Ouma, et.al., 2017). Additionally, it has been observed that mobile money benefits SMEs and entrepreneurial financial inclusion, enhancing resource mobilisation by increasing access to bank credit (Gosavi 2018). Fintech frequently enhances traditional banking services rather than replacing them, as evidenced by Fuster, et. al., (2019). Contrarily, it was suggested that Fintech and big tech lenders provide credit and resources to borrowers

who are typically underserved by banks (Hau, et. al., 2018; Jagtiani and Lemieux, 2018; Sumit, et. al., 2019; Frost, et. al., 2019). Based on this strand of literature, the following hypothesis is framed.

H3: There is a significant relationship between FinTech and financial inclusion.

Key enablers for resource mobilisation

FinTech can help mobilise resources, making financial inclusion a crucial instrument in closing gaps and eliminating biases in the environment (Demertzis, et. al., 2018; Kanga, et.al., 2019). FinTech may bring new life to financial channels like microfinance and crowdfunding (Claessens, et. al., 2018; Manyika, et.al., 2016). Sharma (2016) and Becker (2017) come to the same conclusion that increasing financial inclusion through technology results in more savings, which then results in higher resource mobilisation. Both Chen et al. (2018) and Fine and Chavez (2018) emphasise the importance of FinTech innovations in helping to create the technology required to mobilise resources. FinTech promotes the crowding-in effect seen in emerging economies, particularly in Africa (Gabor, 2019; Michael, 2019). Therefore, it is fair to say that FinTech raises resources from excluded households and distributes resources away from conventional financial intermediaries and lowers transaction costs.

It should be recognized that strong rules and incentives are needed to sustain the benefits of FinTech. To address security and platform concerns, regulations must adapt to technological advances, as well as investor education (Buckley, et.al., 2020; Hodson, 2021). Regulations are important in the FinTech ecosystem since they assist attract funding sources. Regulatory reactions to innovation have a significant impact on both innovative start-ups and incumbent financial services enterprises facing disruption (Arner, et.al., 2015). These technologies must be governed in a balanced and risk-adjusted manner (Zhongming, et.al., 2021). Privacy, data security, cyber security, digital transparency, and the use of financial services and technology to detect money laundering and financial crime are among the other legal and regulatory challenges. Indeed, Regtech - a combination of the phrases "regulatory" and "technology" - has evolved to assist regulators in reducing their reliance on manual entries and lowering costs (Butler and O'Brien, 2019; Buckley, et.al., 2020). It has also been proposed that Regtech will enable regulators to deploy an ever-expanding range of regulatory tactics to keep up with market change (Arner, et.al., 2016). Comprehensive digital infrastructure and well-designed data policies are required to fully exploit Fintech to achieve financial inclusion goals and reduce inequality. Policymakers must create an enabling environment for digital financial innovation that is based on transparency and trust (Setiawan, et.al., 2020; Goo, et. al., 2020).

A growing body of evidence suggests that education is one of the most important drivers of financial inclusion and well-being. Informed financial judgements have been proven to be an important aspect of making wise financial decisions (Lusardi and Mitchell, 2014). Also, differences in financial understanding explain a major portion of wealth disparities in retirement (Lusardi, et.al., 2017). FinTech is crucial in developing the next generation of financial instruments as well as encouraging and facilitating financial education. Increased financial and technological literacy enables individuals to engage with FinTech more effectively (Aun, 2017). Furthermore, the role of financial institutions is critical for the development of supply-side solutions that improve financial literacy and minimise inequalities. Indeed, persons with little financial literacy have been proven to be influenced by the format in which financial information is presented (Hastings and Tejeda-Ashton, 2008; Hastings and Mitchell, 2018).

Another important element impacting resource distribution is financial deepening, which can provide households and enterprises with greater access to resources to meet their financial

needs. Financial deepening (captured by credit) combined with more equitable financial systems can reduce inequality while enhancing resource allocation (Dabla-Norris et.al., 2015). Evidence suggests that financial deepening and FinTech can increase top incomes during the early phases of development, widening the income gap (Roine, et.al., 2009; Claessens and Perotti 2007). To reduce inequality, financial deepening must be complemented by greater financial inclusion. Therefore, based on this discussion, the following hypothesis can be formulated.

H4: Regulatory quality, education, and financial deepening significantly influence the FinTech-financial inclusion-inequality relationship.

The conceptual framework of the study is shown in Figure 1.

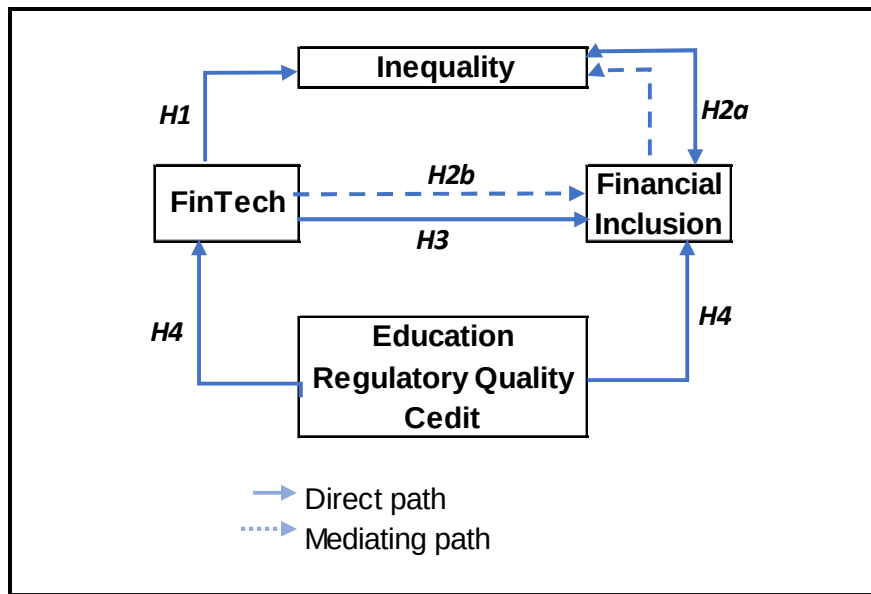


Figure 1: Conceptual Framework of study

3. Methodology

This section discusses the research methodology including the data, sources, and the econometric techniques.

3.1 Data

In this paper, we construct the digital financial inclusion index and traditional financial inclusion index to measure financial inclusion. The digital financial inclusion index is constructed using *mobile cellular subscriptions, access to the Internet (% age 15+), mobile money account (% age 15+), made or received a digital payment (% age 15+), using a mobile phone or the internet to pay bills (% age 15+), and used a mobile phone or the internet to check account balance(% age 15+)*. The traditional financial index is constructed using *commercial bank branches (per 100,000 adults), automated teller machines (ATMs) (per 100,000 adults), financial institution accounts (% age 15+), ownership of a credit card/debit card (% age 15+), savings at a financial institution (% age 15+), borrowed from a formal financial institution (% age 15+), savings using a savings club or a person outside the family (% age 15+), and borrowed from family or friends (% age 15+)*. FinTech is measured by *mobile phones/fixed-line subscriptions*. The different dimensions of inequality are measured by *gender inequality (Gender inequality index), income inequality (Average income of the top 10 percentile/ average*

income of the bottom 10 percentile), and carbon inequality (Top 10 percentile carbon emitters). The various indicators (Appendix A) were chosen because to our knowledge they are the only ones available and to which we have access. For our empirical analysis, we collected data from three main sources, namely: the Global Financial Inclusion Database (FinIndex) for our FinTech and financial inclusion variables; the World Inequality Database for inequality, and the World Development Indicators Database for the other variables. The data was collected for 113 countries and the years 2011, 2014, 2017, and 2021.

3.2 Model

This section presents the empirical approach. First, in equation (1), we examine the influence of FinTech on financial inclusion. Second, in equation (2), we focus on the various dimensions of inequality, and study if FinTech exacerbates or reduces such biases.

The following model specification to examine the influence of FinTech on financial inclusion is as follows.

$$FI_{it} = c + \beta_1 X_{it} + \beta_2 Fintech_{it} + \alpha_i + \epsilon_{it} \dots \dots \dots (1)$$

where FI is either the digital or traditional financial inclusion index; 'Xs' are the controls, which include per capita income growth, credit to the private sector (as a % of GDP), education level (tertiary), regulatory quality, population growth; and FinTech is the respective FinTech proxy listed in Appendix A. The control variables were chosen following the literature (OECD, 2012; Dabla-Norris et al. 2015). For instance, per capita income growth can lessen inequality and increase financial inclusion. However, if low-income households do not benefit from per capita income growth, it may raise inequality (Beck, et. al., 2007). Education has been found to play a significant role in lowering income disparity because it influences career decisions and employment prospects and because it is a key determinant of productivity in the labour market. (Jaumotte, et.al., 2013; Neaime and Gaysset in 2018; Park and Mercado in 2018).

Traditional and digital financial inclusion is estimated using the Principal Component Analysis (PCA). It is a common technique for minimizing the dimensionality of a dataset by data extraction for hidden features and correlations, as well as deleting data with too much information (Yoshino and Taghizadeh-Hesary, 2015; Jolliffe, 2011; Ang 2010). The detailed methodology is discussed in Appendix B.

To determine the impact of FinTech and financial inclusion on various dimensions of inequality, we develop the following model:

$$Inequality_{it} = c + \beta_1 X_{it} + \beta_2 Fintech_{it} + \beta_3 FI + \alpha_i + \epsilon_{it}$$

where inequality refers to gender inequality, income inequality, and carbon inequality; FinTech denotes the proxy; FI refers to traditional or digital financial inclusion; and X represents a set of control variables that are commonly used in the recent finance-inequality literature (Beck, et.al., 2007; Jaumotte, et.al., 2013; Dabla-Norris et al. 2015c; Neaime and Gaysset 2018; Park and Mercado 2018; Asongu and Odhiambo 2019; Hermes 2014; Lacalle-Calderon et al. 2019). We use lagged values of the control variables to avoid potential endogeneity problems.

Our modelling seeks to examine the following dimensions. First, we test how FinTech affects financial inclusion. We do so by running a panel data regression by regressing financial inclusion indices on FinTech proxy and other control variables. Second, we test whether and how FinTech affects inequality (gender, income, and carbon) and does financial inclusion have a moderating role in explaining this relationship.

However, regression analysis does not accommodate multiple dependent variables in a relationship. Therefore, to accurately model causal mechanisms of FinTech, financial inclusion, and inequality, Structuring Equation Modelling (SEM) is applied. According to Hair et al. (2010), SEM is a multivariate technique combining aspects of factor analysis and multiple regressions that will enable us to simultaneously examine a series of interrelated dependence relationships among the variables. The SEM approach is well suited to capture the moderating effect through two effects. These include the direct effect of the independent variable on the outcome variable and the mediated effect of an independent variable through a mediator on the outcome variable.

Hair et al. (2010) argue that a condition of full mediation is achieved when the direct effect becomes non-significant in the presence of the indirect effect, whereas partial mediation occurs when the direct effect is reduced but remains significant. The model fit is assessed by reporting the χ^2 value and degrees of freedom, the comparative fit index (CFI) or Tucker- Lewis index (TLI), and the root mean square error of approximation (RMSEA).

4. Results and findings

Appendix C shows the descriptive statistics of the data used in this study. We ran a panel regression with fixed effects to understand how FinTech influences financial inclusion using the traditional and digital financial inclusion index. As shown in Table 1, the coefficient of the FinTech proxy is statistically significant with traditional and digital financial inclusion. These findings support the emerging research and imply that FinTech has a favourable impact on financial inclusion (Sahay et al. 2020; Mbiti and Weil, 2011; Gosavi 2018; Senyo and Osabutey, 2020). In emerging nations that have pioneered numerous innovations, including mobile payments (Kenya), digital land registration (India), and e-commerce (China), the phenomenon of leapfrogging is easily visible, which has provided a stronger impetus for the proliferation of FinTech and financial inclusion.

Table 1: The impact of FinTech on financial inclusion

Explanatory variables	Traditional Financial Inclusion	Digital Financial Inclusion
FinTech	0.182*** (0.06)	0.95*** (0.313)
Population growth	0.002*** (0.004)	0.003* (0.001)
GDP per capita growth	0.0003* (0.0046)	-0.002 (0.001)
Education	0.125*** (0.017)	0.295*** (0.067)
Regulatory quality	0.53*** (0.047)	0.703** (0.359)
Credit/GDP	0.184* (0.04)	-0.446* (0.241)
Constant	-0.145 (0.03)	-0.606 (0.212)

Robust standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1)

Table 2 presents the results of the regression analysis for gender, income, and carbon inequality. The results indicate that FinTech increases income inequality, decreases gender inequality and has no significant influence on carbon inequality. Education significantly reduces income inequality, while robust regulatory quality in a country significantly reduces

all dimensions of inequality. The results also indicate that the ratio of credit to GDP significantly reduce income inequality.

Table 2: The impact of FinTech on inequality

Explanatory variable	Gender Inequality	Income Inequality	Carbon Inequality
FinTech	-0.046** (0.181)	7.88*** (2.87)	25.35** (13.26)
Population growth	0.0003 (0.002)	0.20 (0.28)	-0.16 (0.125)
GDP per capita growth	-0.0004 (0.0005)	-0.001 (0.002)	0.008 (0.008)
Education	-0.60** (0.031)	0.03 (0.679)	-8.44 (2.10)
Regulatory quality	-0.74*** (0.108)	-12.29*** (2.59)	-40.02** (12.48)
Credit/GDP	0.196 (0.152)	-6.29*** (2.17)	-5.99 (11.40)
Constant	0.56 (0.03)	20.58 (1.67)	-5.88 (8.31)

Robust standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1)

In the next stage, we complement the set of regressors by entering the traditional and digital financial inclusion index in the model as presented in Table 3. Digital financial inclusion significantly reduces the various dimensions of inequality. Further, digital financial inclusion has reduced the coefficient value of FinTech (7.88 to 7.50) indicating that the income inequality-inducing influence of FinTech reduces marginally when directed through digital financial inclusion initiatives. It is also seen that digital financial inclusion has increased the coefficient value of FinTech (-0.046 to -0.433) indicating that the gender inequality-reducing influence of FinTech increases when directed through digital financial inclusion initiatives. Digital financial inclusion, however, does not influence carbon inequality. Traditional financial inclusion significantly reduces income inequality but increases carbon inequality. These results provide preliminary evidence that the impact of FinTech on inequality, especially gender and income is mediated by financial inclusion, and financial inclusion is a key channel through which FinTech affects inequality.

Table 3 :The impact of FinTech and financial inclusion on inequality

Explanatory variable	Gender Inequality	Income Inequality	Carbon Inequality
FinTech	-0.433** (0.184)	7.50*** (2.91)	-1.3 (11.24)
Digital Financial Inclusion	-0.058** (0.03)	-0.55* (0.59)	-10.5*** (2.11)
Traditional Financial Inclusion	-0.187 (0.137)	-5.89* (2.26)	26.11*** (7.87)
Population growth	0.003 (0.01)	0.007 (0.014)	-0.093 (0.104)
GDP per capita growth	-0.0004 (0.0005)	-0.008 (0.0014)	0.018 (0.047)
Education	-0.326 (0.033)	0.769 (0.727)	-4.17** (1.874)
Regulatory quality	-0.57*** (0.131)	-9.05*** (2.76)	-34.02*** (10.37)

Credit/GDP	-0.24** (0.147)	-5.68* (2.18)	2.82 (8.85)
Constant	0.824 (0.084)	19.5 (1.70)	1.909 (6.64)
R-square	0.43	0.2	0.81

Robust standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1)

These findings are consistent with the results obtained by other recent studies (Mookerjee and Kalipioni 2010; Kim 2016; Park and Mercado 2018; Turégano and Herrero 2018; Kai and Hamori 2009; Hermes 2014; Lacalle-Calderon et al. 2019; Khandker 2005; Mahjabeen 2008; Zhang and Posso 2019). We also find that regulatory quality plays a significant role in reducing different dimensions of inequality (Shaban, et.al., 2020; Barajas, et.al., 2020; Delis et.al 2015; Batuo and Asongu 2015; Kouadio and Gakpa 2022). Private sector credit reduces gender and income inequality; and while education significantly reduces carbon inequality (Chundakkadan and Sasidharan; 2022; Khan et.al., 2022; Hassan et.al., 2022).

Although we find some preliminary evidence of the influence of FinTech and financial inclusion on various dimensions of inequality, the results do not accurately model causal mechanisms of FinTech, financial inclusion, and inequality. Therefore, in order to better capture the inter-relationships we apply SEM to enable us to simultaneously examine a series of interrelated dependence relationships among the variables. Mediation analysis is appropriate when there is no direct association established between two variables and it can be proved that the influence of one of these variables on the other variable is transmitted through the third variable known as the mediator (Obagbuwa et al., 2021). In such cases, the third variable might either entirely or partially moderate the relationship, depending on whether the direct path of the primary two variables became statistically significant (Obagbuwa et al., 2021). For ease of analysis in the SEM modelling, a composite financial inclusion index is constructed using the digital and traditional financial indices by applying the PCA.

FinTech-financial inclusion-income inequality relationship

The study tested the hypothesis (H1) to establish whether there is a relationship between FinTech and income inequality. The results of the estimated SEM model as presented in Table 4 revealed that there is a statistically significant direct path running from FinTech to income inequality. The relationship is positive ($\beta = 15.607$) indicating that FinTech increases income inequality. This is contrary to expectations indicating that FinTech does not in itself translate to income inequality reduction. The failure of financial technology to directly reduce income inequalities implies that financial systems may be benefiting the rich at the expense of the poor and worsening income disparities. The empirical findings complement the findings of Altunbaş and Thornton (2019), according to which an increase in any type of financial development is associated with an increase in income inequality.

The second hypothesis (H2a) investigated whether there is a relationship between financial inclusion and income inequality. The SEM results discovered that there is a direct path running from financial inclusion to income inequality indicating that an increase in financial inclusion reduced income inequality ($\beta = -23.717$). This is consistent with the evidence provided by previous studies (Honohan 2007, Mookerjee and Kalipioni 2010, Hermes 2014, Sahay et al. 2015, Kim 2016, Aslan et al. 2017, Park and Mercado 2018, Turégano and Herrero 2018). The study also found a direct path running from income inequality to financial inclusion indicating that an increase in income inequality strengthens financial inclusion ($\beta = 0.016$). This suggests that a certain degree of income inequality can provide incentives to financial inclusion (Lazear and Rosen 1981; Barro 2000). The study also tested the hypothesis (H2b) that there was a

mediating effect of financial inclusion in the relationship between FinTech and income inequality. The study did not find statistically significant evidence to support this hypothesis.

Table 4: Direct and Indirect effects of SEM model

Variable	Direct effect	Hypothesis	Indirect effect	Hypothesis
FinTech				
Education	-0.022	Not supported	0	No path
	(-0.018)		(no path)	
Regulatory quality	0.156***	H4 supported	0	
	(0.029)		(no path)	
Credit	0.100***	H4 supported	0	
	(-0.034)		(no path)	
Financial Inclusion				
FinTech	0.053**	H3 supported	0.000	Not supported
	(0.118)		(-0.001)	
Income inequality	0.016***	H2a supported	0	
	(0.003)		(-0.001)	
Education	0.184***	H4 supported	0.005	
	(0.042)		(-0.006)	
Regulatory quality	0.614***		-0.031	
	(0.079)		(-0.025)	
Credit	0.227***		-0.007	
	(0.081)		(-0.012)	
Income inequality				
FinTech	15.607***	H1 supported	-3.296	Not supported
	(3.895)		(2.301)	
Financial Inclusion	-23.71***	H2a supported	6.403	
	(3.335)		(2.481)	
Population growth	0.057	Not supported	0.015	
	(0.032)		(0.015)	
GDP per capita growth	-0.002		0.001	
	(0.003)		(0.001)	
Education	0	No path	-2.925 ***	H4 supported Mediation through Financial Inclusion
	(no path)		(0.791)	
Regulatory quality	0		-8.714***	
	(no path)		(1.584)	
Credit	0		-2.697**	
	(no path)		(1.481)	

Robust standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1)

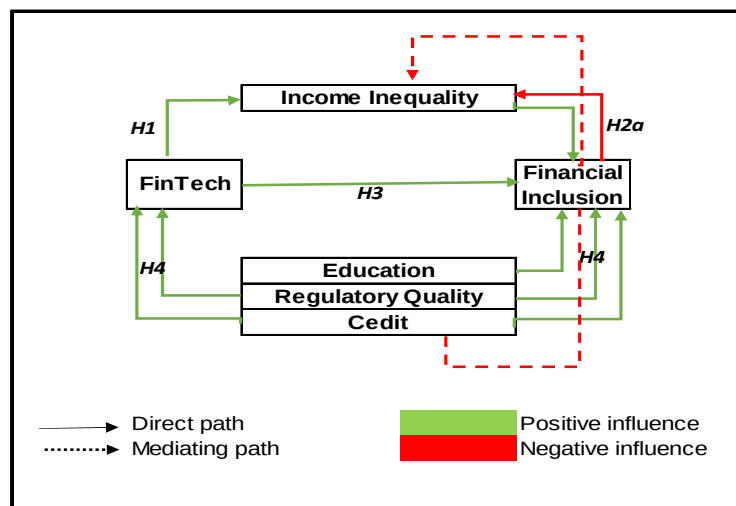
The SEM model further tested if there is a relationship between FinTech and financial inclusion (H3). The results showed that there is a statistically significant direct indicating that FinTech increases financial inclusion ($\beta = 0.053$). This is consistent with the findings of numerous earlier studies (Jack and Suri 2011; Mbiti and Weil 2011; Ghosh 2016; Gosavi 2018; Tchamyau, et.al., 2019; Sahay, et.al., 2020).

Finally, the study investigated if regulatory quality, education, and financial deepening (measured as the ratio of credit to GDP) influenced the FinTech-financial inclusion-inequality relationship (H4). The model indicates a statistically significant direct path running from the regulatory quality and credit to FinTech. This implies that better regulatory quality ($\beta=0.15$) and availability of credit ($\beta=0.1$) improved the proliferation of FinTech (Buckley, et.al., 2020;

Hodson, 2021; Arner, et.al., 2015; Dabla-Norris et.al., 2015). Direct paths were also running from education to financial inclusion. Evidence suggested a positive influence of education on financial inclusion ($\beta = 0.184$). This echoes suggestions to combine education with broader concepts of financial awareness and decision-making (Coulibaly, 2022; Seghers et al., 2012). Statistically direct paths from regulatory quality ($\beta=0.614$) and credit ($\beta=0.227$) to financial inclusion indicate that robust regulations and easier access to credit can enable financial inclusion.

Apart from the direct paths to test the stated hypotheses (H1 to H4), the mediation analysis also established how financial inclusion is performing a mediation role between education and income inequality; regulatory quality and income inequality; and credit and income inequality. The indirect path analysis revealed a negative relationship ($\beta = -2.925, -8.714, \text{ and } -2.697$ respectively) reflecting that education, better regulatory quality and access to credit will lead to a reduction in income inequality through financial inclusion.

The model provided the goodness of fit for the construct measures between the model and the observed data. Indeed, this was justified by a $\chi^2 = 10.998$ (degrees of freedom 6, probability level 0.1). The TLI was 0.954 above the recommended 0.95 and the CFI was 0.985 above the recommended 0.90 (Hu and Bentler, 1999; Xia and Yang; 2019). The RMSEA was 0.043 below the recommended cut-off point of 0.08 (Hu and Bentler, 1999; Xia and Yang; 2019). Based on the SEM modelling, the FinTech-financial inclusion-income inequality nexus is presented in Figure 2.



. Figure 2: Conceptual model (FinTech-financial inclusion-income inequality)

FinTech-financial inclusion-gender inequality relationship

The study tested the hypothesis (H1) to establish whether there is a relationship between FinTech and gender inequality. The results of the estimated SEM model as presented in Table 5 revealed that there is no statistically significant direct path running from FinTech to gender inequality.

The second hypothesis (H2a) investigated whether there is a relationship between financial inclusion and gender inequality. The SEM results discovered that there is a direct path running from financial inclusion to gender inequality indicating that an increase in financial inclusion reduced gender inequality ($\beta = -1.036$). Evidence suggests that financial inclusion reduces the cost of financial intermediation for women and alters consumer behaviour (Arner et al., 2020, Philippon, 2020, Sahay et al., 2020, Boot et al., 2021; Carlin et al., 2019, Breza et al., 2020).

The study also established a statistically significant direct path running from gender inequality to financial inclusion ($\beta = 3.045$). This suggests gender inequality can highlight the existing disparities and provide more financial tools which can help women included in the formal financial system (Adegbite and Machete, 2020; Ndoya and Tsala, 2021). This can also tackle the tradition of women being more relied on informal credit and banks are generally geared towards men and formal businesses, ignoring women, who make up a sizable and growing percentage of the informal sector (Demirgüç-Kunt, 2013; Forge and Vu, 2020). The study also tested the hypothesis (H2b) that there was a mediating effect of financial inclusion in the relationship between FinTech and gender inequality. We find that FinTech reduces gender inequality ($\beta = -0.218$) through financial inclusion. Some studies argue that women are often more concerned about the implications of data sharing for their safety (Armantier et al., 2021), which may prevent the widespread use of financial technology. Also, the adoption of technology might vary by gender and depend on how simple it is to use and how much it delivers better products (Riquelme and Rios, 2010; Thakur, 2020).

Table 5: Direct and Indirect effects of SEM model

Variable	Direct effect	Hypothesis	Indirect effect	Hypothesis	
FinTech					
Education	0.042	Not supported	0	No path	
	(0.035)		(no path)		
Regulatory quality	0.159**	H4 supported	0		
	(0.075)		(no path)		
Credit	-0.114	Not supported	0		
	0.127)		(no path)		
Financial Inclusion					
FinTech	2.536**	H3 supported	2.326	Not supported	
	(1.209)		(1.138)		
Gender inequality	3.045**	H2a supported	2.312		
	(1.392)		(1.352)		
Education	0.426**	H4 supported	0.315		
	(0.220)		(0.199)		
Regulatory quality	2.817***		2.105		
	(1.155)	(1.139)			
Credit	-0.511	Not supported	0.364		
	(0.692)		(0.558)		
Gender inequality					
FinTech	-0.546	Not supported	-0.218*	H2b supported mediation through Financial Inclusion	
	(0.336)		(0.303)		
Financial Inclusion	-1.036 ***	H2a supported	0.786	Not supported	
	(0.159)		(0.204)		
Population growth	0.018	Not supported	0.015		
	(0.006)		(0.015)		
GDP per capita growth	0.001		0.001		
	(0.003)		(0.001)		
Education	0	No path	-0.138 ***	H4 supported Mediation through Financial Inclusion	
	(no path)		(0.046)		
Regulatory quality	0		-0.823 ***		
	(no path)		(0.108)		
Credit	0		0.214		Not supported

	(no path)		(0.177)	
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Robust standard errors in parentheses (*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$)

The SEM model further tested if there is a relationship between FinTech and financial inclusion (H3). The results showed that there is a statistically significant direct indicating that FinTech increases digital financial inclusion ($\beta = 2.536$). This is consistent with the findings of numerous earlier studies (Jack and Suri 2011; Mbiti and Weil 2011; Ghosh 2016; Gosavi 2018; Tchamyou, et.al., 2019; Sahay, et.al., 2020).

Finally, the study investigated if regulatory quality, education, and financial deepening (measured as the ratio of credit to GDP) influenced the FinTech-financial inclusion-inequality relationship (H4). The current model also indicates a statistically significant direct path running from regulatory quality to FinTech. This implies that better regulatory quality ($\beta = 0.159$) improved the proliferation of FinTech by supporting the information environment, setting standards for disclosure, and promoting credit information-sharing systems (Buckley, et.al., 2020; Hodson, 2021; Arner, et.al., 2015). Direct paths were also running from education ($\beta = 0.426$) and regulatory quality ($\beta = 2.817$) to improving financial inclusion. This indicates that robust regulations and education can improve financial inclusion by protecting creditor rights, regulating business conduct, and overseeing recourse mechanisms to protect consumers (Bazarbash, and Beaton, 2020).

Apart from the direct paths established to test the stated hypotheses (H1 to H4), the path analysis also established how financial inclusion is performing a mediation role between regulatory quality and gender inequality; and education and gender inequality. The indirect path analysis revealed a negative relationship ($\beta = -0.823$ and $\beta = -0.138$ respectively) suggesting that improved regulatory quality and education will lead to a reduction in gender inequality through financial inclusion. This likely reflects the fact that while financial innovations has accelerated, financial inclusion has also been able to keep pace with it.

The model provided the goodness of fit for the construct measures between the model and the observed data. Indeed, this was justified by a $\chi^2 = 13.5$ (degrees of freedom 6, probability level 0.107). The TLI was 0.969 (above the recommended 0.95) and the CFI was 0.940 (above the recommended 0.90). The RMSEA was 0.049 (below the recommended cut-off point of 0.08). Based on the SEM modelling, the FinTech-financial inclusion-gender inequality nexus is presented in Figure 3.

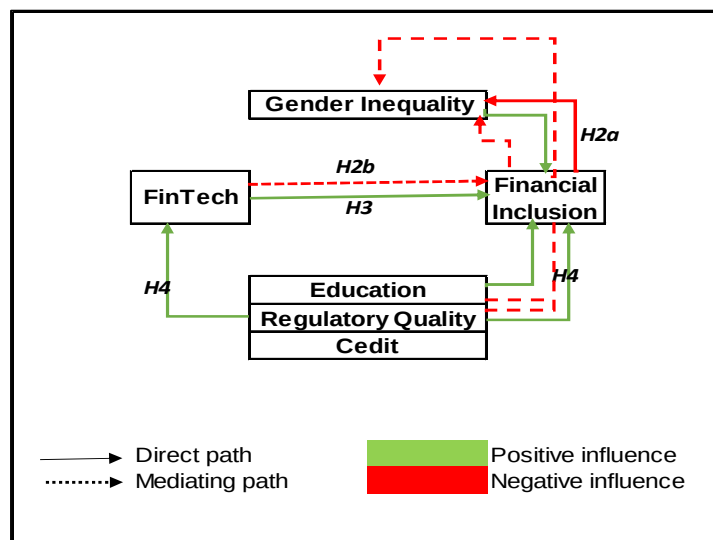


Figure 3: Conceptual Model (FinTech-financial inclusion-gender inequality)

FinTech-financial inclusion-carbon inequality relationship

The study tested the hypothesis (*H1*) to establish whether there is a relationship between FinTech and carbon inequality. We do not establish any direct path between the variables as seen in the results presented in Table 6. The second hypothesis (*H2a*) investigated whether there is a relationship between financial inclusion and carbon inequality. The SEM results discovered that there is a direct path running from financial inclusion to carbon inequality indicating that an increase in financial inclusion reduced carbon inequality ($\beta = -114.76$). This was suggested in other studies as well (Renzhi and Baek, 2020; Zaidi and Hassan, 2021; Odhiambo et. al., 2020). The study also tested the hypothesis (*H2b*) that there was a mediating effect of financial inclusion in the relationship between FinTech and carbon inequality. The study did not find statistically significant evidence to support this hypothesis.

Table 6: Direct and Indirect effects of SEM model

Variable	Direct effect	Hypothesis	Indirect effect	Hypothesis
FinTech				
Education	0.042	Not supported	0	No path
	(0.035)		(no path)	
Regulatory quality	0.159***	H4 supported	0	
	(0.075)		(no path)	
Credit	-0.114	Not supported	0	
	(0.127)		(no path)	
Financial Inclusion				
FinTech	1.761	H3 supported	-1.488	Not supported
	(1.184)		(1.084)	
Carbon inequality	0.036	Not supported	0.029	
	(0.021)		(0.020)	
Education	0.072	Not supported	-0.046	
	(0.193)		(0.157)	
Regulatory quality	2.087**	H4 supported	-1.632	
	(1.077)		(1.064)	
Credit	2.146*		-1.754	
	(1.223)		(1.175)	
Carbon inequality				
FinTech	10.50	Not supported	31.387	Not supported
	(33.448)		(32.775)	
Financial Inclusion	-114.76***	H2a supported	-92.156	
	(15.439)		(21.754)	
Population growth	-1.353	Not supported	0.015	
	(0.591)		(0.015)	
GDP per capita growth	-0.255		0.001	
	(0.263)		(0.001)	
Education	0	No path	3.383	H4 supported Mediation through Financial Inclusion
	(no path)		(4.628)	
Regulatory quality	0		-53.821***	
	(no path)		(9.757)	
Credit	0		-43.742**	
	(no path)		(16.432)	

Robust standard errors in parentheses (*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$)

The SEM model further tested if there is a relationship between FinTech and financial inclusion (H3). The results showed that there is a statistically significant direct indicating that FinTech increases financial inclusion ($\beta = 1.761$). This is consistent with the findings of numerous earlier studies (Jack and Suri 2011; Mbiti and Weil 2011; Ghosh 2016; Gosavi 2018; Tchamyou, et.al., 2019; Sahay, et.al., 2020).

Finally, the study investigated if regulatory quality, education, and financial deepening (measured as the ratio of credit to GDP) influenced the FinTech-financial inclusion-inequality relationship (H4). The model indicates a statistically significant direct path running from the regulatory quality and credit to FinTech. This implies that better regulatory quality ($\beta=2.087$) and availability of credit ($\beta=2.146$) improved the proliferation of FinTech (Buckley, et.al., 2020; Hodson, 2021; Arner, et.al., 2015; Dabla-Norris et.al., 2015; Mehrotra, 2019; Ozili, 2018; Chen and Jin, 2017).

Apart from the direct paths, the mediation analysis also established how financial inclusion is performing a mediation role between regulatory quality and carbon inequality; and credit and carbon inequality. The indirect path analysis revealed a negative relationship ($\beta = -53.821$ and $\beta = -43.742$) suggesting that improved regulation and credit will lead to a reduction in carbon inequality through financial inclusion.

The model provided the goodness of fit for the construct measures between the model and the observed data. Indeed, this was justified by a $\chi^2 = 8.443$ (degrees of freedom 6, probability level 0.208). The TLI was 0.98 (above the recommended 0.95) and the CFI was 0.979 (above the recommended 0.90). The RMSEA was 0.07 (below the recommended cut-off point of 0.08). Based on the SEM modelling, the FinTech-financial inclusion-carbon inequality nexus is presented in Figure 4.

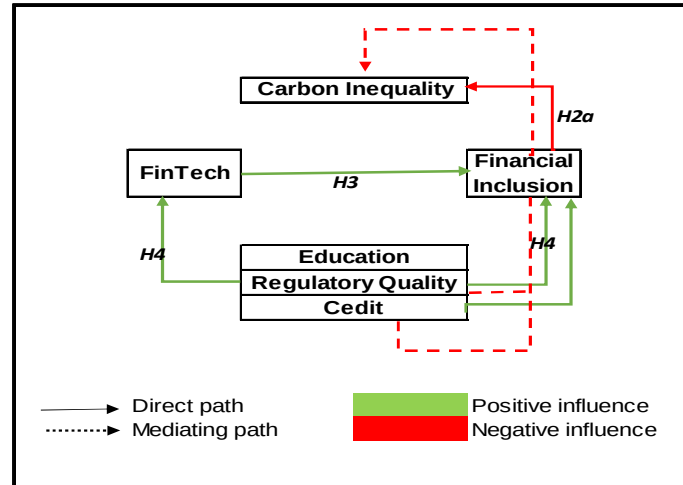


Figure 4: Conceptual Model (FinTech-financial inclusion-carbon inequality)

5. Conclusion

This study created a novel conceptual model and used structural equation modelling to examine the interplay between financial technology, financial inclusion, and various dimensions of inequality in a panel of 113 countries using four waves of survey data from the Global Findex database that cover the years 2011, 2014, 2017, and 2021. Our research makes a unique contribution by looking at the joint dynamics of the various constructs to provide a holistic view of what factors reduce or exacerbate different dimensions of inequality. From the results of our empirical analysis, we can draw the following conclusions.

We find that FinTech increases income inequality while decreasing gender inequality (through financial inclusion). It does not affect carbon inequality. We could argue that, while increasing returns to scale brought by technology can reduce search costs and provide households with better advice, it may not diminish inequality across all categories. Fintech is frequently viewed as a viable strategy for lowering inequality, and according to Bartlett et al. (2018), its algorithms exhibit considerably less discrimination. Fintech's ability to boost participation does not, however, imply that financial technology will lessen inequality for all groups.

We find strong evidence to suggest that FinTech promotes financial inclusion. FinTech can reduce transaction costs, making financial intermediation affordable for segments of the public that previously regarded it to be too expensive. FinTech helps businesses by cutting the cost of business-related payments and allowing small businesses to participate in e-commerce. FinTech has developed an environment that allows economic agents to engage the formal financial system directly, for example through mobile money, bypassing more traditional inclusion methods like bank accounts. Fintech has reduced information asymmetry, and the COVID-19 pandemic has helped significantly to highlight Fintech's positive contributions in a variety of ways.

Financial inclusion reduces all dimensions of inequality. Interestingly, some degree of income and gender inequality incentivises financial inclusion and provides impetus to create inclusive financial policies. Financial inclusion is a crucial component of inclusive growth because economic agents with access to money can make long-term consumption and investment decisions, participate in productive activities, and deal with unforeseen short-term shocks. Inclusive finance has the potential to expand community access to financial services, particularly for the poor and excluded populations who have restricted access to financial services. Access to safe, simple, and well-functioning financial systems for the poor, disadvantaged areas, and struggling industries is required to accelerate growth and reduce inequality

Regulatory quality, education, and access to credit reduce different dimensions of inequality through financial inclusion. These empirical results further highlight the role of key enablers in understanding the FinTech-financial inclusion-inequality nexus. These results add to a modest but growing body of work on the role of FinTech and financial inclusion in fostering better resource distribution and inclusive development across countries. Moreover, this is the first study to investigate different dimensions of inequality and model inter-relationships.

The findings of our study have significant policy ramifications. First, to promote inclusive growth, policymakers must consider strategies to combat various forms of inequality. Our empirical findings show how FinTech, and financial inclusion may influence inequality through many channels. As a result, the nature of suitable policies will inevitably differ among countries and will also need to account for country-specific policy and institutional frameworks, as well as capacity limits. Second, developing more inclusive financial systems that directly benefit the poor and low-income groups, women, and other vulnerable households through expanded access to appropriate financial services should be a priority for financial sector policies targeted at reducing inequality. FinTech has the potential to significantly improve access while also expanding the utilisation of financial products and services. Third, our findings point to FinTech-driven financial inclusion as a viable policy for lowering inequality. However, the same inequalities may expand in the future due to a lack of necessary infrastructure, geo-political tensions, non-green FinTech solutions, etc. Therefore, policies need to strike a balance between fostering stability, and inclusion, while encouraging innovation and creativity.

Appendix A : Summary of variables

FinTech	Digital financial inclusion	Traditional financial inclusion	Measures of divide
Mobile phones/fixed line subscriptions	Mobile cellular subscriptions	Commercial bank branches (per 100,000 adults)	Gender inequality (Gender inequality index)
	Has access to the Internet (% age 15+)	Automated teller machines (ATMs) (per 100,000 adults)	Income inequality (Average income of the top 10 percentile/ average income of the bottom 10 percentile)
	Mobile money account (% age 15+)	Financial institution account (% age 15+)	Carbon inequality (Top 10 percentile carbon emitters)
	Made or received a digital payment (% age 15+)	Owns a credit card/debit card (% age 15+)	
	Used a mobile phone or the internet to pay bills (% age 15+)	Saved at a financial institution (% age 15+)	
	Used a mobile phone or the internet to check account balance(% age 15+)	Borrowed from a formal financial institution (% age 15+)	
		Saved using a savings club or a person outside the family (% age 15+)	
		Borrowed from family or friends (% age 15+)	

Appendix B: *Indexing strategy using Principal Component Analysis (PCA)*

Financial inclusion is difficult to quantify in a straightforward manner. However, the interaction of several causative variables is thought to determine this variable. Financial inclusion, we believe, demonstrates a latent structure that cannot be examined directly but can be inferred from other variables. In the estimation of any latent variable, two essential concerns arise: the selection of relevant variables and the assignment of weights. To get the most information out of a data set included in an index, the weights assigned to the indicators or sub-indices are crucial. A good composite index should include relevant information from all the indicators while not being heavily weighted in favour of one or more of them.

As an indexing technique, the current paper uses a two-stage principal components methodology to evaluate financial inclusion. PCA is a common technique for minimizing the dimensionality of a dataset by data extraction for hidden features and correlations, as well as deleting data with too much information. PCA unlike other linear transformation methods, does not have a fixed set of basis vectors. Furthermore, Yoshino and Taghizadeh-Hesary (2015) found that PCA can discover the interrelationship between the multiple models constructed. PCA is a popular method for analysing explanatory data. It displays the structure of the database and explains inconsistencies as a projection approach (Jolliffe, 2011). PCA has been found to be suitable in the investigation of phenomena influenced by several financial variables. For example, Ang and McKibbin (2007) utilised this method to create the Malaysian financial depth and financial repression indexes. Ang (2010) used this method to create a financial liberalisation index to study the influence of research activities and financial sector reforms on South Korean creative activity.

To determine the applicability of the data, two tests were run at the start of the PCA: Bartlett's test of sphericity and Kaiser-Meyer-Olkin (KMO) test. The Bartlett sphericity test determines whether the correlation matrix used in the PCA is an identity matrix and whether it is significant (Hair, et. al., 2006; Tabachnick, et. al., 2007). The Kaiser-Meyer-Olkin (KMO) test was used to determine the sampling adequacy in the meanwhile. The KMO index varies from 0 to 1, with values greater than 0.5 indicating that the analysis is appropriate (Hair et al., 2006; Tabachnick et al., 2007).

We followed the methodologies of Sarma (2008) and Camara and Tuesta (2014) to create the financial inclusion index. Like Sarma (2008), the dimensions for each sample of our financial inclusion index is calculated as-

$$X_{i,d} = \frac{x_i - m_i}{M_i - m_i} \dots\dots\dots(1)$$

where x_i is the actual value of indicator i , m_i is the minimum value of indicator i , M_i is the maximum value of dimension i . $X_{i,d}$ is the standardized value of indicator i of dimension d . We use principal component analysis, such as Camara and Tuesta (2014), to aggregate each indicator to a dimension index. We denote λ_j ($j = 1, \dots, p$) as the j^{th} eigenvalue, subscript j refers to the number of principal components that also coincides with the number of standardized indicators p . We assume that $\lambda_1 > \lambda_2 > \dots > \lambda_p$ and denote P_k ($k = 1, \dots, p$) as the k^{th} principal component. We derive each dimension index according to the weighted averages:

$$D_d = \frac{\sum_{j,k=1}^p \lambda_j P_k}{\sum_{j=1}^p \lambda_j} \dots\dots\dots(2)$$

where D_d is dimension d index and $P_k = X\lambda_j$. λ_j represents the weights and X is the indicators matrix. The larger proportion of the variation in each dimension is explained by the first

principal component. Once we have the dimension indices financial inclusion index is calculated as in Equation 2,

$$FI_i = \frac{\sum_{j=1}^p \lambda_j P_{ki}}{\sum_{j=1}^p \lambda_j} \dots\dots\dots(3)$$

Where FI_i is the financial inclusion index (traditional or digital) for country i. $P_k = X\lambda_j$ where λ_j represents the dimension weights and X is the dimensions matrix. Equation 3 can be rewritten as follows

$$FI_i = w_1 D_{1,i} + w_2 D_{2,i} + w_3 D_{3,i} + \dots w_k D_{ni} \dots\dots\dots(4)$$

where w_k are the weights derived from PCA and Di are the dimensions. Equation 4 states that the financial inclusion index is a weighted average of individual dimensions.

Appendix C: Summary statistics of the variables

Variables	Mean	Standard Deviation
Traditional FI	0.33	0.19
Digital FI	0.27	0.34
FinTech	0.36	0.12
Population growth	0.04	0.13
GDP, per capita growth	0.54	0.17
Credit/GDP	0.21	0.18
Education	0.28	0.35
Regulatory quality	0.55	0.22
Gender Inequality	0.33	0.20
Income Inequality	15.3	7.6
Carbon Inequality	24.3	21.5

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