Economic Journal of Emerging Markets, 15(2) 2023, 143-159

EJEM
Econ.J.Emerg.Mark.

Economic Journal of Emerging Markets
Available at https://journal.uii.ac.id/jep

Measuring fintech-driven financial inclusion for developing countries: Comprehensive Digital Financial Inclusion Index (CDFII)

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Article Info

Article history:
Received 30 June 2023
Accepted 09 October 2023
Published 31 October 2023

JEL Classification Code:
C43, G21, O33.

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DOI: 10.20885/ejem.vol15.iss2.art3

Abstract

Purpose — The main objective of this study is to develop a comprehensive digital financial inclusion index (CDFII) that accounts for technology-driven financial inclusion and to compare it with a traditional financial inclusion index (TFII) to enhance the measurement of fintech-driven financial inclusion across countries.

Methods — The study employs a three-stage principal component analysis (PCA) to construct the CDFII and TFII using the latest available data from 31 developing countries during the period 2015-2021. The CDFII incorporates a new sub-index measuring individual literacy levels for using financial services, along with existing sub-indices capturing the penetration, availability, and usage of DFS. By integrating digital financial inclusion (DFII) and TFII, the overall CDFII is estimated.

Findings — The findings reveal that the levels of DFII and CDFII are higher than TFII for most of the economies examined. This indicates the significant impact of technology-driven financial inclusion in expanding access to formal banking and non-banking financial services for previously unbanked populations.

Implication — The study implies that policymakers and researchers should prioritize the integration of technology-driven financial inclusion indicators, such as the comprehensive digital financial inclusion index (CDFII), into their assessments and interventions to ensure a more accurate and effective approach to promoting inclusive and sustainable economic development.

Originality — This study introduces the CDFII as a novel comprehensive index that addresses the shortcomings of traditional financial inclusion indices. By incorporating individual skill levels and considering dimensions specific to DFS, the CDFII provides a more accurate representation of fintech-driven financial inclusion levels. This contributes to the existing literature on financial inclusion measurement and provides a valuable analytical tool for researchers and policymakers.

Keywords — Financial inclusion, fintech, digital financial services, comprehensive digital financial inclusion index

Introduction

Financial technology has revolutionized the provision of financial services, enabling financial institutions to reach a wider population more efficiently and cost-effectively. Fintech solutions, delivered through digital platforms, offer fast and user-friendly access to financial services, making them a transformative force for financial inclusion (FI). Recognizing the significance of FI, the

P ISSN 2086-3128 | E ISSN 2502-180X

United Nations has included it as a target in the Sustainable Development Goals (SDGs) (UN, 2015), considering it as a catalyst for poverty alleviation, economic growth, gender equality, and innovation. Fintech has the potential to enhance access to financial services, particularly for the unbanked and underserved populations, with a significant focus on women (Blancher et al., 2019; Lukonga, 2018; Tarazi & Breloff, 2010). These technological advancements enable individuals to overcome barriers such as geographical distance, limited physical infrastructure, and high transaction costs, fostering greater financial inclusion. Furthermore, fintech solutions expand the availability and efficiency of financial services, reaching previously excluded segments like small and medium-sized enterprises (SMEs) and individuals with limited credit history. Digital lending, crowdfunding, and peer-to-peer lending platforms enable access to capital and financial resources, stimulating entrepreneurship and economic growth. Additionally, fintech empowers individuals through digital financial education and literacy initiatives, equipping them with the necessary tools to make informed financial choices, manage their finances, and plan for the future. This knowledge enables individuals to navigate the complexities of the financial system, improve their financial well-being, and contribute to their overall economic empowerment.

While existing studies predominantly measure FI using conventional indicators, limited attention has been given to quantifying the impact of technology-enabled financial inclusion. Existing studies such as Beck et al. (2007), Cámara and Tuesta (2014), Honohan (2008), Sarma (2012), and World Bank (2013) measure FI using conventional indicators such as access to financial services and usage of financial products. Some studies have examined digital financial inclusion by considering indicators related to mobile financial services (Davidovic et al., 2019; Sy et al., 2019). Yet, it is crucial to recognize that information and communication technology (ICT) and digital literacy play essential roles in facilitating digital financial inclusion. Access to mobile and internet services directly influences the usage of financial services, as it reduces transaction costs (Blancher et al., 2019). Moreover, the level of digital and financial literacy significantly affects individuals' ability to effectively engage with digital financial services. However, these dimensions have been largely overlooked in previous FI measurement frameworks.

Constructing a digital financial inclusion index (DFII) is crucial for accurately assessing and monitoring financial inclusion initiatives. Such indices enable policymakers, researchers, and development practitioners to measure the extent of digital financial inclusion in a comprehensive and standardized manner, facilitating cross-country comparisons and the identification of best practices. This information, in turn, informs evidence-based policymaking and the design of targeted interventions to address gaps and barriers that hinder digital financial inclusion. Additionally, a digital financial inclusion index sheds light on the impact of fintech in expanding access, availability, and usage of financial services. It provides valuable insights into the effectiveness of technology-driven initiatives and guides the allocation of resources and investments to maximize positive outcomes. Furthermore, constructing such an index enables the identification of specific dimensions and indicators of digital financial inclusion that require attention and improvement. This knowledge fosters innovation and collaboration among stakeholders, including financial institutions, fintech companies, regulators, and policymakers, all working towards advancing inclusive financial systems. Thus, the underlying research question of the study is: how do traditional financial inclusion indices fail to capture the impact of technology-driven financial inclusion, and how can a comprehensive digital financial inclusion index (CDFII) address these limitations to provide a more accurate measurement of fintech-driven financial inclusion across countries?

To address these gaps, this study aims to develop a comprehensive digital financial inclusion index (CDFII) by integrating dimensions of access, availability, and usage of both digital financial services (DFS) and traditional financial services (TFS), along with measures of digital and financial literacy. The primary contribution of this research is the creation of a digital financial inclusion index (DFII) that incorporates ICT indicators and skill levels alongside existing DFS dimensions. Additionally, a traditional financial inclusion index (TFII) is constructed using established TFS dimensions. By integrating DFII and TFII, the CDFII is calculated for a panel dataset of 31 developing countries from 2015 to 2021. The index is estimated using a three-stage principal component analysis (PCA), utilizing data from the Financial Access Survey (FAS) of the

International Monetary Fund (IMF), World Telecommunication/ICT Indicators, and the Human Development Index (HDI) Database.

Exiting literature defines financial inclusion as a multifaceted concept that lacks a universally agreed-upon definition. However, it generally encompasses actions aimed at facilitating individuals' access to and usage of affordable financial products and services offered by banks and non-bank financial institutions (NBFIs), with a particular emphasis on reaching the unbanked and underserved populations (de Koker & Jentzsch, 2013; Sahay et al., 2015; Sarma & Pais, 2008; World Bank, 2018). In a similar vein, digital financial inclusion (DFI), enabled by fintech, refers to the swift and convenient access to financial services (e.g., savings, loans, money transfers, insurance, e-payments) through digital channels such as mobile phones (both application-based and non-application based) and computers or laptops connected to the internet. In the context of DFI, both fintech companies and traditional financial institutions bear the responsibility of providing financial services to existing and potential business and individual customers. DFI is widely recognized as a vital driver of sustainable development by policymakers and researchers alike (Tay et al., 2022).

Numerous studies have attempted to measure financial inclusion using various indicators and methodologies. Many of these measures focus on a single aspect of financial services, such as the number of bank branches, ATMs, or accounts per person (Beck et al., 2007; Honohan, 2008). Recognizing the limitations of relying on a single indicator, Sarma (2012) and Sarma and Pais (2008) proposed a comprehensive framework that considers three dimensions: penetration (measured by deposit accounts per 1000 adults), availability (number of branches, sub-branches, or offices of financial institutions and ATMs per adult), and usage (total deposit and credit as a percentage of GDP). This framework weighted each dimension using subjective values assigned based on the Human Development Index (HDI) approach. Building on Sarma's work, Gupte et al. (2012) developed an index that combined four components: outreach, usage, value of financial transactions, and transaction cost. Similarly, Park and Mercado (2015, 2018) constructed an index by combining components such as ATMs, branches, creditors, depositors, and the ratio of domestic credit to GDP.

Although these studies have made significant contributions, criticisms arose regarding the equal weighting of components and dimensions of financial services. To address this, Amidžić et al. (2014) and Cámara and Tuesta (2014) employed Factor Analysis (FA) and Principal Component Analysis (PCA) methods to determine appropriate weights for each dimension of financial inclusion. However, due to data availability, proxies were used for quality and barrier measurements, which were later criticized by researchers. Consequently, recent studies, including Amidžić et al. (2014) and Mialou et al. (2017), have largely neglected these dimensions when constructing financial inclusion indices.

Over the past decade, mobile money and internet usage have witnessed rapid growth globally, surpassing traditional banking in some countries and capturing a significant portion of the unbanked population, including the poor, students, youth, refugees, and women. However, existing studies have largely overlooked the dimensions of access, availability, and usage of mobile money and internet technology in measuring financial inclusion. Some recent studies, such as Cámara et al. (2017), Manyika et al. (2016), and Sy et al. (2019), have considered mobile money transactions and the number of mobile money accounts as indicators of digital financial inclusion. However, these indicators provide only a limited perspective on the development of digital financial inclusion.

Overall, efforts have been made to develop comprehensive indices for measuring financial inclusion, primarily focusing on traditional financial services. However, there is no consensus on the selection of indicators, dimensions, and measurement approaches, and the inclusion of fintech factors, such as accessibility, availability, and usage of mobile financial services, ICT services, internet usage, e-commerce transactions, and digital literacy, remains lacking (Mialou et al., 2017). A recent study on the developing financial inclusion index by Sahay et al. (2020) only covers the years 2014 and 2017 for 52 emerging developing countries. Our study aims to address these gaps by considering traditional financial inclusion and digital financial inclusion, as well as the level of skill and knowledge in using these services. By incorporating these factors, our approach provides a comprehensive measure of digital financial inclusion from 2015 to 2023. Table 1 presents a

summary of the literature, including the measurement variables and methodologies used to assess traditional and digital financial inclusion indexes.

Table 1. Review of existing literature: studies, approaches, indicators used to construct FI index

Study	Country, year coverage, data source, Methods/Weight allocation	Dimensions/variables considered for each study
Sarma (2012)	94 countries; 2004 – 2010, FAS; UNDP Approach; Penetration 1, Availability: 0.5 and Usage: 0.5	Banking penetration: Bank accounts per thousand population Availability: Bank branches per 0.1 million population, ATMs per million population. Usage: Credit and Deposits as a % of GDP.
World Bank (2013)	2011; Findex and others; Equal Weights	Bank branches/100,000 adults; Bank accounts/ 1000 population; Market capitalization; Value traded; Yields of public bond; Ratio of private and total debt securities; Enterprises with bank credit (% of all enterprises and small firms); accounts at a formal financial institution (% age 15+)
Cámara and Tuesta (2014)	82 countries; 2011, Findex and FAS; Two-stage PCA	Bank branches/ 100,000 population; ATMs/1000,000 population; ATMs/ 1000 sq km; Bank offices or branches/1000 sq km; Persons who hold at least a minimum financial product (%); Adults Saved at a banks and NBFIs (% age 15+); Loan from a banks and NBFIs (% age 15+); Barriers to FI.
Sahay et al. (2015)	176 countries; 1980 – 2013, FAS and Others; PCA	Bank branches/100,000 adults; Market capitalization; Value traded outside; Total number of debt issuers.
Dabla-Norris et al. (2015)	104 countries; 2011 & 2014; Findex, Enterprise Survey and FAS; Equal weights	Household dimension: Accounts at a bank or NBFI (% age 15+); Saved at a bank or NBFI in the earlier period (% age 15+); Loan from a bank or NBFI in the earlier period (% age 15+); Person credit card taken (% age 15+); Person a debit card taken (% age 15+); ATM as a main channel of withdrawal (% age 15+). SMEs dimension: Companies with a bank loan; Companies with a current or deposit account; Companies using banks to funding & investment; Collateral required for a credit % of the loan amount; Companies not required a credit; Companies identifying cost of investment as a major limitation. Access dimension: Bank branches/100,000 population; ATMs/ 1000,000 population; ATMs/1000 sq km; Bank branches/1000 sq km.
Park and Mercado (2015)	188 economies; FAS; UNDP approach	ATMs per thousand adults; Branches and offices of banks per 0.1 million adults; Creditors per thousand adults, number, from banks; Depositors per thousand adults, number, with banks; Ratio of domestic credit GDP.
Mialou et al. (2017)	31 Nations; 2009 – 2012, FAS; WGM, Factor analysis	Access Dimensions: ATMs per thousand sq km; Bank branches per thousand sq km. Usage dimensions: Resident household depositors, number, with ODCs per thousand adults; Resident household borrowers, number, with ODCs per thousand adults.
Loukoianova et al. (2018)	163 countries, FAS; WGM, Factor analysis	Bank branches, number, per 0.1 million population; ATMs, number, per 1 million population; ATMs, number, per thousand sq km; Bank, number, branches per thousand sq km.

Study	Country, year coverage, data source, Methods/Weight allocation	Dimensions/variables considered for each study
Blancher et al. (2019)	88 Economies, FAS; WGM, Factor analysis	Bank branches, number, per 0.1 million population; ATMs, number, per 1 million population; ATMs, number, per thousand sq km; Bank branches, number, per thousand sq km; Bank depositors, number, per thousand adults; Bank borrowers, number, per thousand adults.
	87 countries, FAS; WGM, Factor analysis	ATMs, number, per thousand sq km; Bank branches, number, per thousand sq km; Bank depositors, number, per thousand adults; Bank borrowers, number, per thousand adults.
	Household Findex; FAS, Enterprise Survey: PCA	Bank branches per 0.1 million population; ATMs per 0.1 million population; Accounts, number, at a bank (% age 15+); Saving accounts, number, at a bank in the earlier period (% age 15+); Loan accounts, number, from a Bank and NBFI in the earlier period (% age 15+); Any money saved last year (% age 15+); Credit card holder (% age 15+); Debit card holder (% age 15+
	SME Findex; FAS, Enterprise Survey	Enterprises with a bank credit (%); Enterprises with a current or deposit account (%); Enterprises using banks for investment (%); Enterprises using banks for working capital (%); Investments disbursed by banks (%); Working capital financed by banks (%).
Ahamed and Mallick (2019)	86 countries over the period 2004–12; FAS; PCA	Outreach: Bank sub-branches or branches and ATMs per 0.1 million people; Bank branches and ATMs per thousand sq km) Usage: Bank accounts per thousand populations.

Methods

This analysis utilizes annual secondary data from the Financial Access Survey (FAS), ITU World Telecommunication/ICT Indicators, and the Human Development Index (HDI) Database of UNDP for the period of 2015 to 2021 in 31 developing countries (Appendix A). However, it is important to note that not all developing economies are included in the analysis due to incomplete or missing data on mobile financial services throughout the years. The selected study period of 2015-2021 was chosen because it provided complete data for the variables considered in each selected country. Additionally, the period was significant as it marked the visible growth of mobile money and internet payment in financial services, particularly in developing countries, as noted by Demirguc-Kunt and Klapper (2012), making it a relevant timeframe for this study.

In constructing composite financial inclusion (FI) indexes, existing studies employ both parametric and non-parametric approaches. Non-parametric approaches rely on subjective judgment to allocate weights to indicators, which introduces bias and makes the index sensitive to small adjustments in weights. To address this, we adopt a parametric approach, specifically Principal Component Analysis (PCA), to determine the appropriate weights for each indicator and develop a comprehensive digital financial inclusion index (CDFII). Through PCA, CDFII is derived as a linear combination of various indices, including the Digital Financial Inclusion Index (DFII) and Traditional Financial Inclusion Index (TFII). This approach ensures a more objective and robust measure of digital financial inclusion. We can express the relationship as:

$$CDFII_{jt} = \omega_{DFII} DFII_{jt} + \omega_{TFII} TFII_{jt} + u_{jt} \quad (1)$$

Where *CDFIIjt* is the comprehensive DFII of country *j* at year *t*; ω_{DFII} and ω_{TFII} are the weights obtained from PCA of the corresponding index *DFII* and *TFII*, respectively; and u_{jt} is the model residuals.

The DFII is defined as the linear combination of four different dimensions (sub-index) such as penetration (D^p), access (D^a) to, usage of (D^u), and level of skill and ICT knowledge of people (SL) of using digital financial services (DFS).

$$DFII_{jt} = \varphi_1 D_{jt}^{p} + \varphi_2 D_{jt}^{a} + \varphi_3 D_{jt}^{u} + \varphi_4 SL_{jt} + \varepsilon_{jt} \quad (2)$$

The TFII could be obtained from the following linear equation where TFII is the function of penetration (T^p), access (T^a) and usage (T^u) dimension (sub-index) of conventional financial services.

$$TFII_{jt} = \mu_1 T_{jt}^{p} + \mu_2 T_{jt}^{a} + \mu_3 T_{jt}^{u} + \vartheta_{jt} \quad (3)$$

Each sub-index is defined as the linear function or combination of the two or more explanatory variables. Therefore, each sub-index of the DFII can be obtained from the following linear equations:

$$D_{jt}^{p} = \alpha_1 MMAC_{jt} + \alpha_2 FBIS_{jt} + \alpha_3 MMT_{jt} + \varepsilon_{1,jt} \quad (4)$$

$$D_{jt}^{a} = \beta_1 MMAG_{jt} + \beta_2 MBS_{jt} + \beta_3 MCTS_{jt} + \beta_4 FTS_{jt} + \varepsilon_{2,jt} \quad (5)$$

$$D_{jt}^{u} = \gamma_1 VMMT_{jt} + \gamma_2 OBMFS_{jt} + \gamma_3 IUI_{jt} + \varepsilon_{3,jt} \quad (6)$$

$$SL_{jt} = \mathfrak{z}_1 EYS_{jt} + \mathfrak{z}_2 MYS_{jt} + \vartheta_{4,jt} \quad (7)$$

Each sub-index of TFII can be estimated through the following system of equations:

$$T_{jt}^{p} = \delta_1 DAC_{jt} + \delta_2 LAC_{jt} + \vartheta_{1,jt} \quad (8)$$

$$T_{jt}^{a} = \zeta_1 BR_{jt} + +\zeta_2 ATM_{jt} + \zeta_3 ATMPSQF_{jt} + \vartheta_{2,jt} \quad (9)$$

$$T_{jt}^{u} = \Omega_1 OD_{jt} + \Omega_2 OL_{jt} + \vartheta_{3,jt} \quad (10)$$

The composition of each dimension and variables considered in this study is described in Table 2.

Table 2. Components/dimensions of CDFII and their notations

Comprehensive Digital Financial Inclusion Index (CDFII)	
Components of DFII	Components of TFII
a) Penetration of DFS (D_{jt}^{p}) - Mobile money accounts, Registered, per thousand adults (MMAC) - Fixed-broadband Internet subscriptions, per thousand inhabitants (FBIS) - Mobile money transactions per thousand adults (MMT)	a) Penetration of TFS (T_{jt}^{p}) - Deposit or savings accounts with FI per thousand adults (DAC) - Loan or Credit accounts with FI per thousand adults (LAC)
b) Availability of DFS (D_{jt}^{a}) - Mobile money agent outlets, registered, per 0.1 million adults (MMAG) - Active mobile-broadband subscriptions, per 100 residents (MBS) - Mobile-cellular telephone subscriptions, Number per hundred inhabitants (MCTS) - Fixed telephone subscriptions per hundred inhabitants (FTS)	b) Availability of TFS (T_{jt}^{a}) - Branches and offices of FI, number, per 0.1 million adults (BR) - Automated teller machines, number, per 0.1 million adults (ATM) - Automated teller machines, per square kilometer (ATMPSQF)
c) Usage of DFS (D_{jt}^{u}) - Transactions of mobile money, value, % of GDP (VMMT) - Outstanding balances with mobile financial services, % of GDP (OBMFS) Individuals using the internet, in % (IUI)	c) Usage of TFS (T_{jt}^{u}) - Deposit (outstanding) with banks, % of GDP (OD) - Loans (outstanding) % of GDP from banks (OL)
d) Level of skill and ICT knowledge for using DFS (SK_{jt}) - Years of schooling, Mean (MYS) - Years of schooling, Expected (EYS)	

Our study aims to develop a comprehensive Fintech-enabled or digital Financial Inclusion Index (CDFII) for selected developing countries using the Principal Component Analysis (PCA) method recommended by Camara and Tuesta (2014). The estimation of CDFII involves a three-stage PCA approach. In the first stage, we intend to find out the value of weights $\alpha, \beta, \gamma, \text{ƹ}, \delta, \zeta$ and Ω using PCA to calculate the dimensions D_j^p, D_j^a, D_j^u, SL_{jt}, T_j^p, T_j^a and T_j^u, respectively. Each dimension contains linear combinations of several explanatory variables or indicators related to entry into, availability, and usage of DFS and TFS ,and the final value of evalution are also called indices. In the second stage, we once again apply the PCA methods to estimate the weights φ_1, $\varphi_2, \varphi_3, \varphi_4, \mu_1, \mu_2$ and μ_3 of corresponding dimensions D_j^p, D_j^a, D_j^u, SL_{jt}, T_j^p, T_j^a ad T_j^u in order to calculate value of DFII and TFII. In the final stage, we apply PCA over again, to obtain the parameters ω_{DFII} and ω_{TFII} of the respective index of DFII and TFII from the Equation (1) and we obtain our ultimate index CDFII. However, before conducting PCA, each indicator is normalized to ensure that all indicators contribute evenly to a scale (0 to 1) when they are added collectively. The final comprehensive index of DFI value lies between 0 to 1, where 0 refers to no tech-enabled FI and 1 indicates high inclusion.

Results and Discussion

Table 3 presents the summary statistics of the individual indicators used in estimating the comprehensive index of Digital Financial Inclusion (DFI). The indicators are categorized into three dimensions for Digital Financial Services (DFS) and Traditional Financial Services (TFS): access, availability, and usage. Additionally, two dimensions are considered for ICT services: access and usage. Furthermore, a single dimension is utilized to measure the skill-level of access to financial/ICT services. The values for each dimension are calculated from the corresponding indicators using Principal Component Analysis (PCA).

Table 3. Summary Statistics

Dimensions	Variable	Obs.	Mean	Std. Dev.	Min	Max
Penetration of DFS (D_{jt}^p)	MMAC	217	537.887	520.946	0.009	2308.780
	FBIS	217	4.034	6.561	0.007	38.772
	MMT	217	20601.130	35001.460	0.145	228876.000
Availability of DFS (D_{jt}^a)	MMAG	217	298.132	353.521	0.826	1583.040
	MBS	217	46.158	29.321	1.330	154.920
	MCTS	217	93.189	35.068	31.541	198.150
	FTS	217	5.347	7.595	0.031	36.885
Usages of DFS (D_{jt}^u)	VMMT	217	17.808	29.182	0.000	177.578
	OBMFS	217	0.297	0.753	0.000	6.158
	IUI	217	35.647	21.816	0.204	87.660
Penetration of TFS (T_{jt}^p)	LAC	217	138.735	153.477	2.905	810.066
	DAC	217	828.102	703.036	32.745	2946.410
Availability of TFS (T_{jt}^a)	BB	217	10.376	10.606	0.837	55.071
	ATM	217	25.872	27.590	0.856	117.792
	ATMPSQF	217	0.126	0.218	0.000	1.000
Usages of TFS (T_{jt}^u)	OD	217	46.463	35.168	5.080	192.782
	OL	217	32.535	25.656	2.798	140.595
Skill Level for using ICT, DFS (SL_{jt})	EYS	217	11.914	2.011	7.349	16.049
	MYS	217	6.990	2.816	1.936	11.572

In this first-stage PCA stage, we measure the sub-indices for the penetration (p), availability (a), and usage (u) dimensions of Digital Financial Services (DFS) and Traditional Financial Services (TFS), as well as the sub-index for the level of skill (SL), using the selected variables mentioned in Equation 4 to 10 in the second column of the summary statistics. Table 4 provides information on the minimum number of principal components that account for the majority variation, along with

their respective highest Eigenvalue (EV), within each dimension. Following Kaiser (1960) criterion, components with an EV greater than one are considered for further analysis.

Table 4. Principal components for different indicators of DFS and TFS

Dimensions	Variables	Component	EV	Difference	Proportion	Cumulative
(1) Digital Financial Services (DFS)						
D_{jt}^{p}	MMAC, FBIS, MMT	C1	1.7	0.8783	0.565	0.565
		C2	0.8	0.3298	0.272	0.837
		C3	0.5		0.162	1
D_{jt}^{a}	MMAG, MBS, MCTS, FTS	C1	2.144	1.150	0.536	0.536
		C2	0.994	0.381	0.248	0.784
		C3	0.613	0.363	0.153	0.938
		C4	0.249		0.062	1.000
D_{jt}^{u}	VMMT, OBMFS, IUI	C1	1.263	0.333	0.421	0.421
		C2	0.930	0.122	0.310	0.731
		C3	0.808		0.269	1.000
(2) Traditional Financial Services (TFS)						
T_{jt}^{p}	LAC, DAC	C1	1.778	1.556	0.889	0.889
		C2	0.222		0.111	1.000
T_{jt}^{a}	BB, ATM, ATMPSQF	C1	2.165	1.662	0.722	0.722
		C2	0.502	0.169	0.167	0.889
		C3	0.333		0.111	1.000
T_{jt}^{u}	OL, OD	C1	1.799	1.598	0.899	0.899
		C2	0.201		0.101	1.000
(3) Level of Skill of ICT and DFS (SL)						
SK_{jt}	EYS, MYS	C1	1.724	1.448	0.862	0.862
		C2	0.276		0.138	1.000

The results indicate that the first principal component (C1) has the highest eigenvalue in all three combinations, which suggests that it explains the maximum amount of variation within each group. Specifically, for the DFS dimensions, C1 explains 42% to 56% of the total variation in the explanatory variables. In the case of Traditional Financial Services (TFS), the first component (C1) accounts for more than 72% of the overall variation in the independent variables. Furthermore, for the skill dimension (SL), C1 explains 86% of the total data variation. Based on these findings, we focus our analysis on the first principal component (C1) for each dimension, as it captures the most significant proportion of variation. We estimate the sub-indices by utilizing the parameters assigned to C1. To further refine the results, we employ orthogonal varimax rotation, which helps determine the weights associated with each C1 and their respective eigenvalues (Table 5).

Our analysis revealed that the first principal component (C1) in the penetration dimension of DFS (D_j^p) is strongly influenced by the variables mobile money account (MMAC) and mobile money transactions (MMT). An increase in the number of mobile money accounts held by unbanked individuals and the volume of transactions conducted through mobile or tech-enabled channels positively contributes to the value of C1. On the other hand, fixed broadband subscription (FBIS) negatively affects C1 which suggests that an increase in fixed broadband subscription (FBIS) is associated with a decrease in the value of C1. Regarding the availability dimension of DFS (D_j^a), mobile-cellular telephone subscriptions play a significant role in C1 (0.608), followed by mobile broadband subscriptions (MBS) and financial transactions through mobile apps (FTS). The presence of mobile phones enables individuals to access mobile financial services via USSD codes

and mobile applications provided by financial service providers. Therefore, an increase in mobile phone users strongly influences the value of the first principal component. In the usage dimension of DFS(D_j^u), the value of mobile money transactions as a percentage of GDP, along with the outstanding balance with mobile financial services (OBMFS), exhibit a strong positive correlation with C1. This is primarily due to the widespread use of mobile or digital platforms for domestic and international remittances, as well as for various financial transactions such as receiving wages, paying for goods and services, and utility bill payments. Conversely, there is a negative correlation between C1 and the number of individuals using the Internet (IUI) for financial transactions, indicating that not all Internet users utilize digital channels for such purposes. in sum, IUI has a negative relationship with C1, indicating a contrasting impact compared to VMMT and OBMFS.

Table 5. Scoring estimates for orthogonal varimax rotation (weights)

Estimate	Variable	C1	Unexplained	KMO	KMO overall
D_{jt}^p	MMAC	0.6417	0.3018	0.557	0.583
	FBIS	-0.4656	0.6325	0.704	
	MMT	0.6095	0.3702	0.568	
D_{jt}^a	MMAG	-0.289	0.820	0.633	0.570
	MBS	0.529	0.400	0.565	
	MCTS	0.608	0.208	0.547	
	FTS	0.517	0.428	0.598	
D_{jt}^u	VMMT	0.607	0.535	0.536	0.542
	OBMFS	0.470	0.721	0.585	
	IUI	-0.641	0.481	0.531	
SL_{jt}	EYS	0.707	0.138	0.500	0.500
	MYS	0.707	0.138	0.500	
T_{jt}^p	LAC	0.707	0.110	0.500	0.500
	DAC	0.707	0.110	0.500	
T_{jt}^a	BB	0.579	0.274	0.690	0.694
	ATM	0.600	0.220	0.653	
	ATMPSQF	0.552	0.342	0.761	
T_{jt}^u	OL	0.707	0.104	0.500	0.500
	OD	0.707	0.104	0.500	

The analysis also reveals that all the explanatory variables in the Level of Knowledge and Skills on Formal Financial Services (SL) dimension, as well as the Penetration (T_j^p) and usage (T_j^p) dimensions of traditional financial services, show positive and equal correlations with the first principal component. Among these variables, the presence of bank branches (BB) and automatic teller machines (ATMs) play a crucial role in determining the availability of traditional financial services. These variables make significant positive contributions to the first component of the Principal Component Analysis (PCA). Specifically, ATMs and CDM (Cash Deposit Machine) devices have a higher impact on the first component compared to bank branches. This is likely because the number of available ATMs and CDM devices surpasses that of traditional bank branches, indicating their greater accessibility in providing financial services.

In the second stage of PCA, we focus on determining the weights (φ and μ) for the sub-indices $D_{jt}^p, D_{jt}^a\ D_{jt}^u,\ SL_{jt},\ T_{jt}^p, T_{jt}^a,$ and T_{jt}^u, which are essential in calculating the DFII and TFII using Equations 2 and 3. Accessing and utilizing digital financial services (DFS) requires individuals to possess certain technological skills, such as using mobile USSD menus, applications, smartphones, the internet, and other computerized channels. The level of technological skills (SL) is a crucial factor in determining individuals' access to the formal financial system (Lenka & Barik, 2018). In our analysis, we approximate technological skills using the education index, which is derived from the PCA. The results presented in Table 6 show the outputs of the PCA. In both

cases, the first principal component (C1) has the highest eigenvalue, exceeding 2, and it accounts for 52.5% and 80.5% of the total data variation in the DFII and TFII analysis respectively.

Table 6. Estimation of PC and eigenvalue of sub-indices of DFII and TFII

Indices	Sub-indices	Component	EV	Difference	Proportion	Cumulative
Digital Financial Services (DFS)						
$DFII$	$D_{jt}^{p}, D_{jt}^{a}, Dt_{j}^{u}, SL_{jt}$	C1	2.100	1.067	0.525	0.525
		C2	1.033	0.519	0.258	0.783
		C3	0.514	0.162	0.129	0.912
		C4	0.353		0.088	1.000
Traditional Financial Services (TFS)						
$TFII$	$T_{jt}^{p}, T_{jt}^{a}, T_{jt}^{u}$	C1	2.414	1.991	0.805	0.805
		C2	0.423	0.261	0.141	0.946
		C3	0.163		0.054	1.000

The scoring coefficients (weights) for each sub-index of the DFII and TFII are presented in Table 7. When measuring DFII, the first principal component (C1) shows a strong positive correlation with two sub-indices. Specifically, C1 increases with the availability of Digital Financial Services (DFS) and the level of skills required for using digital devices. On the other hand, the access and usage dimensions of DFS exhibit a negative correlation with C1. This aligns with expectations as these dimensions heavily rely on the availability of DFS and individuals' proficiency in using mobile USSD, apps, and the internet for cashless transactions. Furthermore, the availability of fintech and technological innovation in financial services plays a crucial role in promoting financial inclusion by ensuring easier and cost-effective access to financial services. This, in turn, can stimulate the growth of non-financial technologies and foster innovation. Collaboration between financial institutions and mobile network operators has resulted in hybrid systems that provide access to formal savings, deposits, credit, and insurance services to both banked and unbanked individuals. Based on the PCA, the index of digital financial inclusion (DFII) has been illustrated in Appendix B.

Table 7. Scoring coefficients (weights) and overall KMO

Estimate	Variable	C1	Unexplained	Overall KMO
DFII	D_{j}^{p}	0.556	0.317	0.657
	D_{j}^{a}	-0.568	0.296	
	D_{j}^{u}	0.602	0.218	
	SL_{j}	0.077	0.036	
$TFII$	T_{j}^{p}	0.595	0.146	0.7005
	T_{j}^{a}	0.597	0.140	
	T_{j}^{u}	0.538	0.301	

Similarly, when measuring TFII, the sub-indices related to the penetration, attainability, and usage of Traditional Financial Services (TFS) are positively associated with the first principal component (C1). The scores of T_{j}^{p}, T_{j}^{a} and T_{j}^{u} contribute to an increase in C1. The penetration index of TFS receives the highest score, followed by the availability and usage index, suggesting that financial services through more traditional channels such as ATMs, bank branches, loans, and savings accounts tend to exhibit better financial inclusion. The index of traditional financial inclusion (TFII) is illustrated in Appendix C. Both appendixes also include the ranking of different countries based on the five-year average of the access, availability, and usage sub-indices of Traditional Financial Inclusion (TFI).

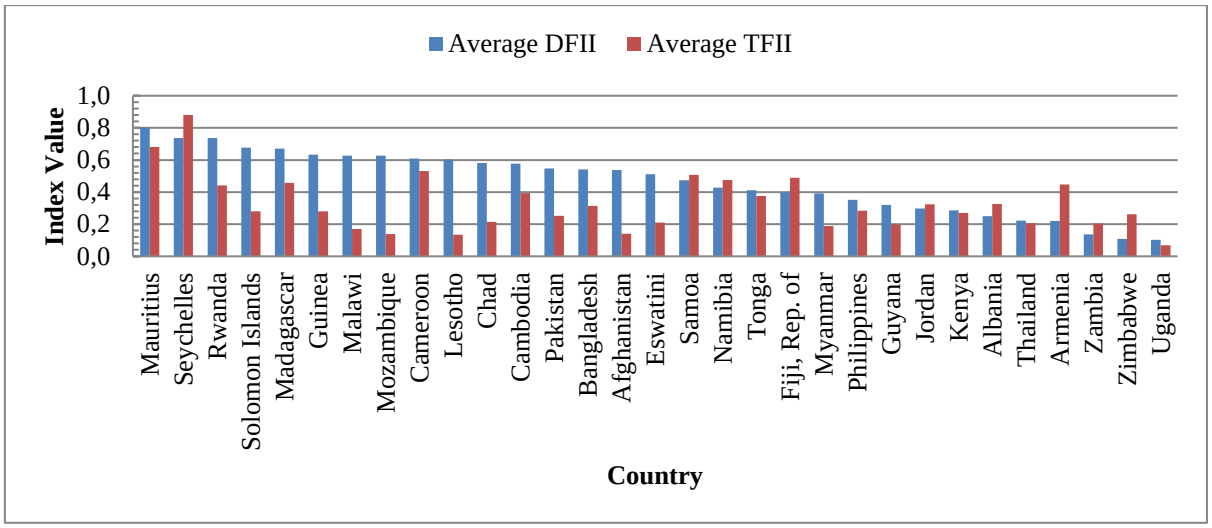

Figure 1. Comparative portrait of DFII and TFII

Additionally, Figure 1 displays a plot diagram illustrating the digital and traditional financial services indices from 2015 to 2021. In most countries, the DFII surpasses the TFII. Mauritius and Seychelles demonstrate equal improvements in both traditional and digital financial services, securing the first and second positions, respectively, in both categories. Notably, there have been changes in the ranking of countries from the third position.

Several factors contribute to the higher values of DFS indices compared to TFS indices. Firstly, the collaboration between mobile money service providers, mobile financial apps, and debit and credit cards has played a significant role. This collaboration has facilitated increased money transfers, withdrawals, and access to financial services through mobile phones and the Internet. The substantial growth in the number of active mobile money users during the study period supports this trend. Mobile money operators have also witnessed significant expansion, contributing to the accessibility and availability of DFS (Shaikh et al., 2023). Secondly, the adoption of technology in providing financial services has seen remarkable progress, mainly due to improved access to technology. Developing countries have experienced a surge in Smartphone users, with mobile phones becoming the primary device for internet access. This shift has led to a substantial increase in the usage of app-based financial services through mobile devices. Moreover, there has been a doubling of domestic and international remittances, utility bill payments, and website-based money transfers across all countries (Pazarbasioglu et al., 2020).

Another contributing factor is the increase in the number of mobile money agents in developing economies. These agents provide services such as bill payments, cash top-ups, cash-outs, and peer-to-peer transactions, which further facilitate the usage of DFS. The number of ATMs and mobile financial services accounts has also shown similar growth globally, indicating the widespread availability of financial services. Furthermore, the rapid diffusion of information and communication technology (ICT) and the growth of mobile phones, personal computers, and internet users in developing countries have played a crucial role. Mobile phone penetration has exceeded fixed-line subscriptions in the past two decades. This shift has allowed previously underserved groups to access and benefit from DFS, reducing transaction costs, particularly associated with managing physical branches. ICT and financial services through mobile phones improve access to deposits, credit, and remittance facilities, leading to the emergence of branchless financial services and promoting digital financial inclusion. Lastly, the improvement in secondary and higher education levels in developing countries has contributed to the higher adoption of mobile financial services. Higher levels of education spread awareness and enhance people's confidence in using mobile banking. A stronger understanding of the different uses and benefits of mobile financial services, particularly among the younger generation, promotes digital financial inclusion through cashless payments (Urhie et al., 2021). These factors collectively contribute to the higher values of DFS indices compared to TFS indices, showcasing the growing importance and impact of digital financial inclusion in various economies

In the third stage of PCA, we measure the Comprehensive Digital Financial Inclusion Index (CDFII) by integrating the values of the Digital Financial Inclusion Index (DFII) and the Traditional Financial Inclusion Index (TFII) obtained in the previous stage. We define the equation as follows:

$$CDFII_{jt} = f\left(DFII_{jt}, TFII_{jt}\right) \quad (11)$$

$$CDFII_{jt} = \omega_{DFII} DFII_{jt} + \omega_{TFII} TFII_{jt} + u_{jt} \quad (12)$$

According to the findings of the PCA presented in Table 8, the first component (C1) has an Eigenvalue of 1.75 and explains 87.7% of the variance. In this stage, we consider two components, DFII and TFII, which were obtained from the second-stage PCA. The overall Kaiser-Meyer-Olkin (KMO) statistic is 0.50, and both components have equal loading scores of 0.7071, with the squared summation of the scores equal to one.

Table 8. Third-stage PCA for measuring comprehensive DFII

Index	Indicators	Component	Eigenvalue	Difference	Proportion	Cumulative	Overall KMO
CDFII	DFII	C1	1.75447	1.50894	0.8772	0.8772	0.50
	TFII	C2	0.24553		0.1228	1	

Table 9. Ranking of countries based on CDFII

Economy	2015	2016	2017	2018	2019	2020	2021	Average	Ranking
Mauritius	0.899	0.896	0.920	0.897	0.918	0.955	0.955	0.920	1
Seychelles	0.765	0.786	0.852	0.890	0.976	1.000	0.984	0.893	2
Thailand	0.756	0.781	0.790	0.783	0.803	0.833	0.847	0.799	3
Armenia	0.652	0.675	0.687	0.711	0.731	0.778	0.769	0.715	4
Zambia	0.554	0.537	0.555	0.637	0.693	0.691	0.746	0.630	5
Albania	0.560	0.631	0.627	0.600	0.597	0.625	0.631	0.610	6
Jordan	0.613	0.597	0.612	0.612	0.596	0.620	0.603	0.607	7
Namibia	0.503	0.650	0.597	0.580	0.655	0.620	0.619	0.603	8
Fiji	0.505	0.522	0.559	0.536	0.542	0.542	0.545	0.536	9
Tonga	0.491	0.505	0.553	0.528	0.495	0.547	0.545	0.524	10
Samoa	0.437	0.487	0.489	0.500	0.505	0.529	0.531	0.497	11
Philippines	0.416	0.457	0.481	0.477	0.477	0.506	0.489	0.472	12
Guyana	0.424	0.422	0.427	0.432	0.449	0.510	0.504	0.453	13
Cambodia	0.325	0.327	0.374	0.394	0.382	0.415	0.450	0.381	14
Bangladesh	0.338	0.350	0.346	0.353	0.355	0.427	0.407	0.368	15
Myanmar	0.288	0.323	0.340	0.364	0.376	0.413	0.418	0.360	16
Eswatini	0.340	0.343	0.333	0.324	0.267	0.350	0.418	0.339	17
Pakistan	0.274	0.278	0.282	0.286	0.293	0.303	0.293	0.287	18
Kenya	0.243	0.244	0.253	0.257	0.254	0.292	0.262	0.258	19
Lesotho	0.285	0.276	0.264	0.234	0.209	0.254	0.217	0.249	20
Mozambique	0.312	0.283	0.247	0.250	0.211	0.185	0.164	0.236	21
Afghanista	0.221	0.230	0.234	0.234	0.235	0.240	0.241	0.234	22
Cameroon	0.257	0.258	0.221	0.186	0.154	0.196	0.183	0.208	23
Chad	0.194	0.197	0.202	0.192	0.196	0.215	0.231	0.204	24
Solomon Islands	0.254	0.249	0.273	0.137	0.128	0.200	0.176	0.202	25
Malawi	0.210	0.209	0.198	0.182	0.175	0.184	0.173	0.190	26
Guinea	0.246	0.234	0.209	0.184	0.155	0.137	0.105	0.181	27
Madagascar	0.195	0.174	0.166	0.211	0.136	0.157	0.129	0.167	28
Rwanda	0.190	0.174	0.170	0.158	0.149	0.126	0.085	0.150	29
Zimbabwe	0.073	0.075	0.118	0.131	0.116	0.095	0.120	0.104	30
Uganda	0.135	0.128	0.121	0.107	0.089	0.062	0.027	0.096	31

The first principal component (C1) shows a significant correlation with both the original DFII and TFII indices. An increase in C1 indicates an improvement in both DFII and TFII, suggesting that these two criteria change together. In other words, when one index increases, the

other index tends to increase as well. Thus, C1 serves as a measure of the penetration, access, usage, and skill of both Digital Financial Services (DFS) and Traditional Financial Services (TFS). On the other hand, the second principal component (C2) increases with digital financial inclusion initiatives but decreases with traditional financial services. The Eigenvalue of C2 is negative (-0.7071) indicating a negative impact of conventional and formal financial services, such as services provided through bank branches or requiring physical presence at financial service providers' outlets to access real economic opportunities.

Based on the findings of the PCA in the third stage, we construct the CDFII for the years 2015 to 2021. Table 9 presents the ranking of 31 developing countries based on the average CDFII scores. Mauritius and Seychelles hold the first and second ranks, respectively, while Uganda ranks last.

Conclusion

This study sheds light on the shortcomings of traditional financial inclusion indices in capturing the true extent of technology-driven financial inclusion. It highlights how current indices overlook the contribution of modern technologies like mobile money, internet connectivity, and mobile cellular services. Additionally, the arbitrary assignment of weights to different dimensions of financial inclusion in these indices raises questions and invites debate. The study emphasizes the significant role of mobile phones and other digital devices in improving payment systems and granting easier access to formal banking and non-banking financial services for the unbanked and economically disadvantaged populations. However, traditional financial inclusion indices fail to adequately consider these technological advancements, leading to an inaccurate portrayal of a country's actual level of financial inclusion. Furthermore, previous studies have neglected the influence of people's knowledge and education when calculating financial inclusion indices, despite these factors being essential determinants of financial inclusion.

To address these limitations, this study introduces a novel comprehensive digital financial inclusion index (CDFII) that incorporates individual skill levels and dimensions related to the penetration, availability, and usage of digital financial services (DFS). The study also constructs a traditional financial inclusion index (TFII) that focuses solely on traditional financial services (TFS) without considering the skill dimension. By integrating DFII and TFII, the overall CDFII is calculated, revealing significantly higher levels of digital financial inclusion compared to traditional financial inclusion for each economy examined. However, it is important to note that this study has its limitations, including the limited coverage of only 31 countries due to data availability on DFS indicators. Moreover, the study's dataset includes a wide range of countries, encompassing both developing and emerging economies, which may introduce disparities and outliers that could potentially impact the generalizability and robustness of the findings.

The proposed CDFII serves as a valuable analytical tool for researchers and policymakers, enabling them to measure and compare fintech-driven financial inclusion levels across countries. This comprehensive index provides a more nuanced understanding of the impact of technology on financial inclusion and can inform targeted interventions aimed at enhancing access, availability, and usage of digital financial services. Ultimately, the adoption of such interventions can contribute to inclusive and sustainable economic development. Future research should aim to expand the sample size and incorporate a wider range of countries to enhance the generalizability of the findings. Additionally, ongoing updates to the CDFII are necessary to reflect the evolving landscape of financial technology and digital financial services.

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Appendix A

Table 10. List of developing countries

Afghanistan	Fiji	Mauritius	Seychelles
Albania	Guinea	Mozambique	Solomon Islands
Armenia	Guyana	Myanmar	Thailand
Bangladesh	Jordan	Namibia	Tonga
Cambodia	Kenya	Pakistan	Uganda
Cameroon	Lesotho	Philippines	Zambia
Chad	Madagascar	Rwanda	Zimbabwe
Eswatini	Malawi	Samoa	

Appendix B

Table 11. Ranking of countries based on DFII

Economy	2015	2016	2017	2018	2019	2020	2021	Average	Ranking
Mauritius	0.724	0.736	0.751	0.788	0.821	0.867	0.923	0.801	1
Seychelles	0.731	0.746	0.727	0.735	0.743	0.713	0.760	0.737	2
Rwanda	0.662	0.688	0.692	0.723	0.741	0.789	0.856	0.736	3
Solomon Islands	0.574	0.585	0.549	0.782	0.812	0.696	0.735	0.676	4
Madagascar	0.610	0.644	0.664	0.597	0.725	0.700	0.748	0.670	5
Guinea	0.526	0.544	0.592	0.633	0.681	0.705	0.756	0.634	6
Malawi	0.616	0.610	0.605	0.633	0.643	0.629	0.650	0.626	7
Mozambique	0.507	0.554	0.601	0.595	0.661	0.719	0.746	0.626	8
Cameroon	0.523	0.523	0.583	0.645	0.698	0.634	0.660	0.609	9
Lesotho	0.531	0.546	0.579	0.632	0.671	0.599	0.663	0.603	10
Chad	0.593	0.592	0.582	0.598	0.591	0.565	0.542	0.580	11
Cambodia	0.559	0.585	0.530	0.531	0.581	0.613	0.639	0.577	12
Pakistan	0.555	0.555	0.553	0.555	0.549	0.525	0.541	0.548	13
Bangladesh	0.568	0.558	0.572	0.567	0.571	0.453	0.495	0.541	14
Afghanistan	0.558	0.546	0.537	0.538	0.532	0.527	0.527	0.538	15
Eswatini	0.526	0.533	0.545	0.553	0.577	0.448	0.396	0.511	16
Samoa	0.513	0.480	0.489	0.492	0.481	0.427	0.434	0.474	17
Namibia	0.444	0.414	0.429	0.450	0.453	0.389	0.420	0.428	18
Tonga	0.426	0.409	0.372	0.397	0.462	0.387	0.422	0.411	19
Fiji	0.422	0.417	0.361	0.393	0.381	0.403	0.407	0.398	20
Myanmar	0.478	0.434	0.414	0.387	0.391	0.321	0.324	0.393	21
Philippines	0.412	0.356	0.328	0.338	0.349	0.323	0.352	0.351	22
Guyana	0.371	0.371	0.360	0.351	0.334	0.228	0.229	0.321	23
Jordan	0.266	0.303	0.286	0.291	0.309	0.302	0.329	0.298	24
Kenya	0.217	0.233	0.240	0.261	0.335	0.350	0.375	0.287	25
Albania	0.280	0.260	0.225	0.250	0.262	0.240	0.228	0.249	26
Thailand	0.279	0.237	0.220	0.241	0.212	0.189	0.171	0.221	27
Armenia	0.248	0.229	0.224	0.216	0.228	0.191	0.204	0.220	28
Zambia	0.089	0.107	0.121	0.131	0.161	0.173	0.174	0.137	29
Zimbabwe	0.210	0.196	0.109	0.000	0.023	0.087	0.135	0.108	30
Uganda	0.184	0.160	0.114	0.084	0.058	0.061	0.064	0.104	31

Appendix C

Table 12. Ranking of countries based on TFII

Economy	2015	2016	2017	2018	2019	2020	2021	Average	Ranking
Seychelles	0.749	0.785	0.834	0.869	0.986	0.971	0.973	0.881	1
Mauritius	0.650	0.660	0.698	0.678	0.687	0.695	0.696	0.681	2
Cameroon	0.437	0.459	0.462	0.534	0.544	0.608	0.674	0.531	3
Samoa	0.429	0.493	0.510	0.541	0.537	0.514	0.528	0.507	4
Fiji	0.454	0.486	0.490	0.484	0.481	0.509	0.522	0.489	5
Namibia	0.479	0.464	0.469	0.466	0.483	0.467	0.497	0.475	6
Madagascar	0.253	0.265	0.364	0.445	0.533	0.646	0.694	0.457	7
Armenia	0.405	0.457	0.458	0.463	0.469	0.474	0.406	0.447	8
Rwanda	0.385	0.386	0.398	0.460	0.464	0.471	0.520	0.441	9
Cambodia	0.242	0.283	0.314	0.358	0.400	0.519	0.633	0.393	10
Tonga	0.329	0.337	0.392	0.371	0.349	0.410	0.443	0.376	11
Albania	0.259	0.270	0.304	0.327	0.339	0.370	0.407	0.325	12
Jordan	0.277	0.294	0.304	0.351	0.350	0.343	0.354	0.325	13
Bangladesh	0.285	0.297	0.308	0.316	0.326	0.324	0.338	0.314	14
Philippines	0.244	0.257	0.272	0.276	0.292	0.320	0.321	0.283	15
Guinea	0.233	0.205	0.311	0.313	0.343	0.290	0.271	0.281	16
Solomon Islands	0.208	0.212	0.239	0.235	0.555	0.254	0.256	0.280	17
Kenya	0.207	0.214	0.258	0.252	0.280	0.304	0.380	0.271	18
Zimbabwe	0.221	0.247	0.274	0.250	0.299	0.263	0.277	0.262	19
Pakistan	0.214	0.235	0.240	0.251	0.258	0.284	0.285	0.252	20
Chad	0.152	0.185	0.165	0.234	0.228	0.264	0.273	0.214	21
Eswatini	0.232	0.248	0.242	0.234	0.140	0.147	0.225	0.210	22
Thailand	0.141	0.114	0.185	0.210	0.258	0.261	0.278	0.207	23
Zambia	0.259	0.262	0.251	0.198	0.160	0.166	0.128	0.203	24
Guyana	0.203	0.200	0.194	0.193	0.210	0.197	0.186	0.198	25
Myanmar	0.150	0.166	0.178	0.194	0.177	0.191	0.265	0.189	26
Malawi	0.147	0.156	0.162	0.167	0.189	0.175	0.193	0.170	27
Afghanistan	0.116	0.133	0.125	0.124	0.179	0.138	0.168	0.140	28
Mozambique	0.144	0.144	0.128	0.127	0.131	0.153	0.144	0.139	29
Lesotho	0.117	0.118	0.136	0.143	0.140	0.142	0.146	0.135	30
Uganda	0.049	0.049	0.056	0.076	0.082	0.085	0.086	0.069	31