Sustainable economic development in India: The dynamics between financial inclusion, ICT development, and economic growth

Rudra P. Pradhan[a],*, Mak B. Arvin[b], Mahendhiran S. Nair[c], John H. Hall[d], Sara E. Bennett[e]

[a]Vinod Gupta School of Management, Indian Institute of Technology, Kharagpur, WB 721302, India
[b]Department of Economics, Trent University, Peterborough, Ontario K9L 0G2, Canada
[c]Sunway University Business School, Sunway University, Bandar Sunway, 47500, Selangor, Malaysia
[d]Department of Financial Management, University of Pretoria, Pretoria 0028, South Africa
[e]College of Business, University of Lynchburg, Lynchburg, VA 24501, USA

*Corresponding author. Email: rudrap@vgsom.iitkgp.ernet.in

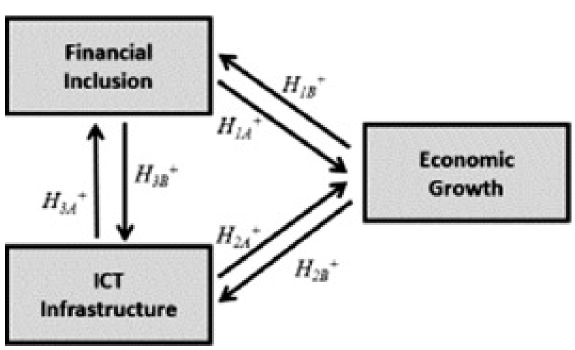
Highlights

- We consider the interdependence between ICT infrastructure, financial inclusion, and economic growth.
- We use data from 20 Indian states from 1991 to 2018.
- We have found endogenous relationships between the variables and have determined the direction of causal links.
- •We suggest policies to elevate economic development to the same level as ICT infrastructure development and financial inclusion.

Abstract

The roles played by the financial sector and of information and communication technology (ICT) in economic growth are well established in the literature. With increasing development and the convergence between the financial and ICT platforms, digital financial systems emerged which have opened new opportunities to close the wealth gaps between the "haves" and "have-nots" in the developing world. In this paper, we examine the short-run and long-run dynamics between economic growth, financial inclusion initiatives, and ICT infrastructure development in 20 Indian states over the period from 1991 to 2018. Using the Granger-causality technique, we show evidence of strong temporal causality between these variables in the short and long term. Our empirical results demonstrate that careful co-curation of ICT infrastructure development, financial inclusion initiatives, and economic growth strategies is essential for these Indian states to achieve sustainable economic development.

Graphical abstract



Keywords: Economic growth; Financial inclusion; ICT infrastructure; India

JEL Classification: O43; O16; E44; E31

1. Introduction

It is widely acknowledged that two vital contributors to economic growth are development in the financial sector and advances in the information and communication technology (ICT) sector. The financial sector adds to economic development in multiple ways, including allocating resources efficiently for productive activities, supplying credit and insurance, enabling savings for a wide segment of the population, and providing risk management for investors (Allen et al., 2018; Ruiz, 2018; World Bank, 2017; Onaolapo, 2015; Schumpeter, 1934). Not only are the services provided by financial institutions critical in increasing the rates of return on investment, but financial institutions also play a crucial role in the implementation of financial inclusion initiatives. The World Bank outlines financial inclusion as a situation where both firms and individuals have access to suitable and affordable financial services and products, enabling them to acquire credit and insurance, undertake financial transactions, make payments, and build savings. These services should be delivered efficiently and sustainably (World Bank, 2017). Financial inclusion initiatives are designed to give marginalized and vulnerable communities access to vital services such as savings accounts, microfinance, home and personal loans, insurance, financial literacy, market intelligence on investment opportunities, and other services to expand their quality of life, all of which supplement wider economic growth.

In this context, ICT can act as a catalyst for economic growth via three channels. Firstly, ICT improves the efficiency of firms, allowing them to increase their market reach and enrich their products (Pradhan et al., 2014; Timmer and Van Ark, 2005; Baily, 2002; Dutta, 2001), and thus enabling them to pursue economies of scale and scope. Secondly, increasingly innovative ICT has resulted in the emergence of new sectors, job creation, and other network spillover effects (Haftu, 2019; Cardona et al., 2013; Nair and Shariffadeen, 2009). This implies that the ICT sector has become an important revenue earner for many countries. Thirdly, ICT is also seen as an important development tool to help to close the socioeconomic divide between the "haves" and "have-nots" in an economic system. Several studies have shown that ICT can provide marginalized and poor communities with access to much-needed education and public services – including financial services (Del Gaudio et al., 2020; Nair et al., 2020; Owusu-Agyei et al., 2020; Lashitew et al., 2019; Mushtaq and Bruneaub, 2019; Njoh, 2018; Urbinati et al., 2018; Asongu and Roux, 2017; Hong, 2017; Berger and Nakata, 2013; Linstone and Phillips, 2013; Betz and Khalil, 2011; Lee et al., 2011; Nair, 2011; Phillips, 2011; Laursen and Meliciani, 2010; Gholami et al., 2009; Wang and Chien, 2007; Carbonara, 2005; Gregorio et al., 2005; Oyelaran-Oyeyinka and Adeya, 2004; Friedman and Deek, 2003; Phillimore, 2001; Howells, 1995).

While there are extensive studies that have investigated the individual effects of the functions of financial inclusion or ICT in contributing to economic growth, there are only a limited number of studies that have analysed the dynamics between ICT and financial inclusion initiatives and their role in deepening the impact of economic growth. The primary objective of our study is therefore to study the relationship between ICT, financial inclusion, and economic growth in the context of a developing country, namely India.

The reason for choosing India is that it is the fifth-biggest country in the world. India has a nominal GDP of USD 2.94 trillion (World Population Review, 2020a) and a population of 1.38 billion (World Population Review, 2020b). India's economy is regarded as ICT-savvy, but the question arises of how effective the ICT revolution that swept across this country has been in providing financial services to the population, and whether it has contributed to the increased economic growth of the country. International Telecommunication Union (ITU) statistics show that India has made significant progress in the adoption of key ICT technologies, namely mobile phones and internet adoption. For example, mobile phone use per 100 inhabitants increased from 0.34 in 2000 to 86.94 in 2018, while internet use as a percentage of the population increased from 0.53 percent in 2010 to 34.45 percent in 2017 (ITU, 2020).

A large percentage of India's population has bank accounts, thanks to several government initiatives over the last decade. In fact, according to the Global Findex Database 2017, about 80% of the adult population in India has a bank account (World Bank Group, 2018). However, the actual use of banking systems in India has lagged significantly. For example, in 2017, only 29% of adults in India with a bank account made or received online payments, only 12% used a debit card, and only 7% used the internet or a mobile phone to check their bank account balances, and 39% made neither a withdrawal nor a deposit (World Bank Group, 2018). This suggests that a significant percentage of the population in India does not benefit from the basic use of financial services, let alone from drawing on the more sophisticated services available. In India, different states have varying levels of ICT adoption rates and financial inclusion. Lower-income states in India have lower levels of ICT adoption and financial inclusion than higher-income states (Agarwal and Panda, 2018). Hence, there is a significant incentive to fast-track financial inclusion and economic opportunities in this digital economy. Utilizing the available potential can increase economic growth in the various states across India, despite their different stages of development.

The aim of the present study is to ascertain the dynamic and endogenous associations between financial inclusion, ICT infrastructure, and economic growth in India. Unlike earlier studies in this literature, we examine the temporal causal links between these three variables *simultaneously*. Causality is defined here in a *temporal* and not a philosophical sense; that is, our notion of causality is one of Granger causality. The results from our study can be used as a blueprint for other developing economies around the world to illustrate the importance and use of financial inclusion and ICT infrastructure to reduce the gap between the "haves" and "have-nots".

The remainder of our study is arranged in five sections. A brief discussion of the background literature and a discussion of our hypotheses are presented in Section 2. Section 3 describes the empirical approach used to observe the short-run and long-run associations between the variables. Section 4 sets out the empirical results. Lastly, we propose numerous policy implications in light of the observed results and the final insights in Section 5.

2. Contextual literature and development of hypotheses

The roles of financial inclusion and ICT as two key economic development tools to increase countries' wealth has aroused considerable interest, which is reflected in the literature. The literature documents causal associations between financial inclusion and economic growth, and between ICT and economic growth. One area that is not well studied in the literature is the causal linkages concerning financial inclusion and ICT *development*. In this section, we examine all three relationships and outline the hypotheses that are examined in this study.

2.1. Links between economic growth and financial inclusion

Financial inclusion is usually recognized as the availability of formal financial services (e.g., saving opportunities, credit, and insurance) to the wider population, as such inclusion has been recognised to be a critical engine of economic growth (Pradhan and Sahoo, 2020; Sethi and Acharya, 2018; Nirupam and Chhikara, 2013; Hyytinen and Toivanen, 2005). The function of financial inclusion in propelling economic growth is both direct and indirect, as Fig. 1 shows.

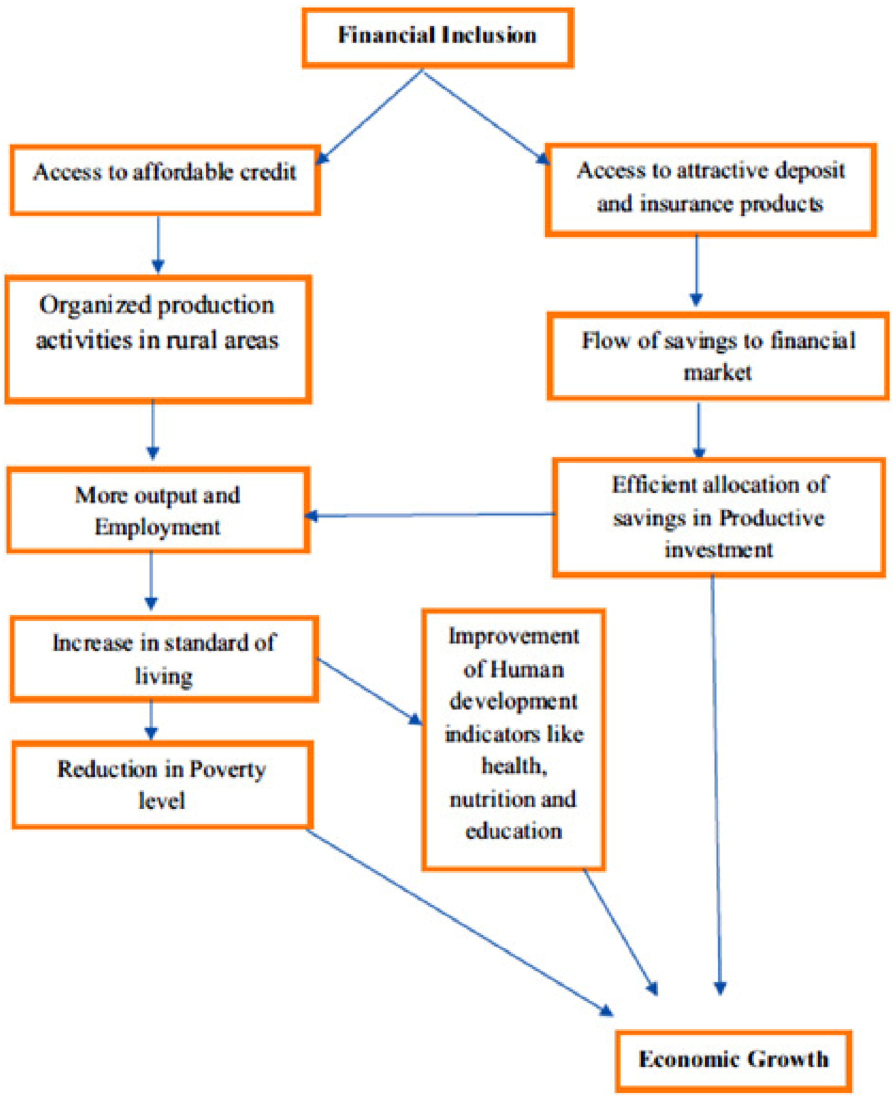


Fig. 1. The analytical framework between financial inclusion and economic growth **Sources**: Constructed by the authors using analysis in Mushtaq and Bruneaub (2019), Sethi and Acharya (2018), Kodan and Chhikara (2013), Rajan (2009), Nirupam et al. (2008), World Bank (2008), Claessens and Perotti (2007), ADB (2000), and Levine (1997).

The association between economic growth and financial inclusion is captured in two opposing positions in respect to causality.

The first is unidirectional causality from financial inclusion towards economic growth, expressed in the *financial inclusion-driven economic growth hypothesis*, which proposes that financial inclusion initiatives Granger-cause economic growth. The rationale for the hypothesis is that access to the necessary credit and the other supporting financial services mentioned above enables economic agents to use the financial resources optimally to develop their businesses and invest in ventures that yield high returns on investment that are of value to society. This then in turn improves the competitiveness of the industry and increases the quality of life for all, especially for vulnerable communities. These outcomes lead to higher economic growth. Studies that support this relationship include those by Kapoor (2019), Mushtaq and Bruneaub (2019), Raza et al. (2019), Sethi and Sethy (2019), Sharma (2019), Siddik et al. (2019), Kodan et al. (2008), Ozili (2018), Kim et al. (2017), Lenka and Sharma (2017), Okoye et al. (2017), Kim (2015), Sarma and Pais (2011), Atindéhou et al. (2005), and King and Levine (1993a, 1993b, 1993c).

The second school of thought advances a unidirectional interconnection from economic growth towards financial inclusion, the *economic growth-driven financial inclusion hypothesis*. In this scenario, it is economic growth that Granger-causes financial inclusion. The line of argument for this hypothesis is that increasing economic activities raise the demand for new financial services, and these services are then used by a wider segment of the population. Essentially, these factors lead to wider coverage by financial services, thus increasing financial inclusion in the economy. Increasing wealth in the country should also bring about greater investment and eventually more advanced financial services can be provided that increase socioeconomic reach and wealth. Thus, strong economic growth is postulated to intensify financial inclusion initiatives. Studies that show this relationship include those by Pradhan et al. (2020a), Kim et al. (2018), Pradhan et al. (2018), Pradhan et al. (2013), Pradhan and Arvin (2016), Nkwede (2015), Sahay et al. (2015), Nirupam and Chhikara (2013), Mohan (2006), and the IMF (2005).

Based on the discussion above, we test the following hypotheses:

H_{1A}^{+}: Financial inclusion (positively) Granger-causes economic growth.

H_{1B}^{+}: Economic growth (positively) Granger-causes financial inclusion.

2.2. Links between economic growth and ICT infrastructure

The literature on the dynamics between ICT infrastructure development and economic growth is discussed in this section. A synopsis of these dynamics is provided in Fig. 2.

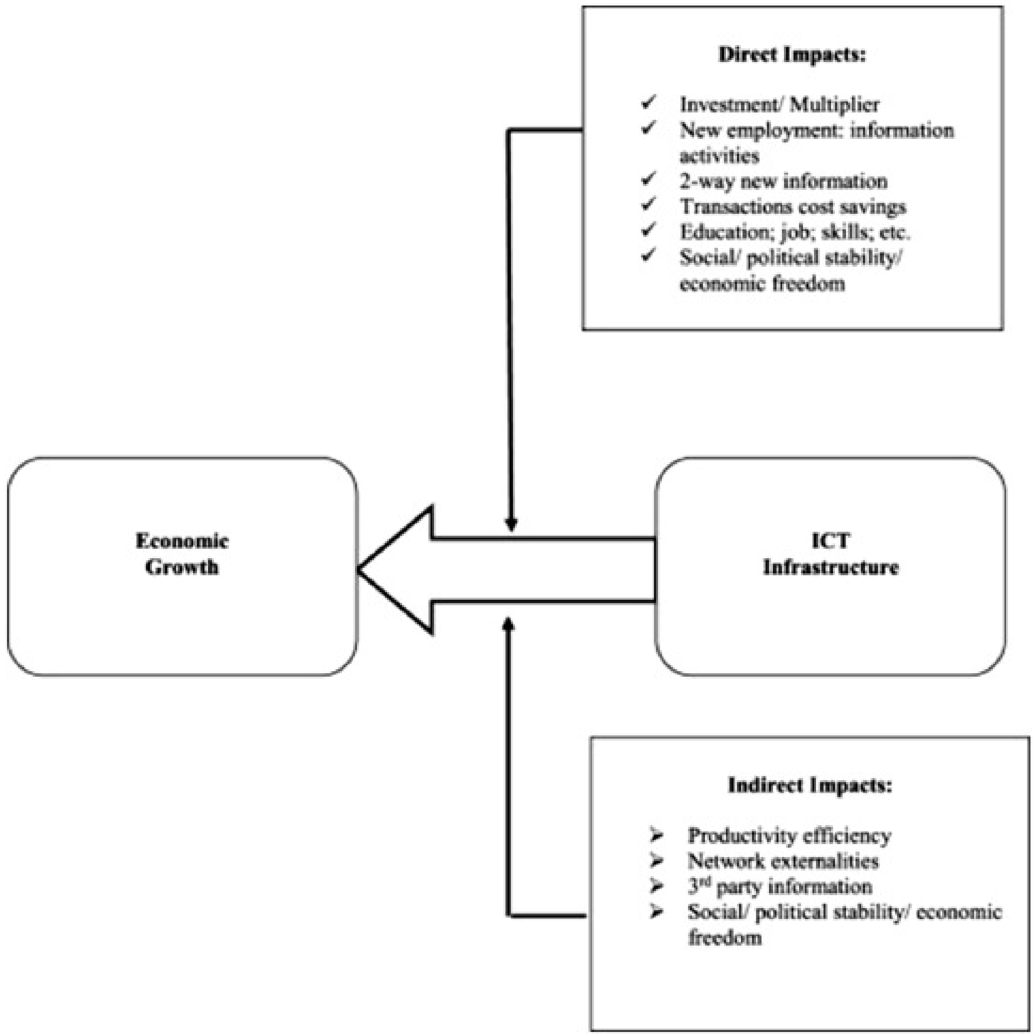


Fig. 2. The analytical framework between ICT infrastructure and economic growth **Sources**: Constructed by the authors using analysis in Pradhan et al. (2014), Pradhan et al. (2014), Thompson, Jr. and Garbacz (2007), and Dutta (2001).

There are again two schools of thought that describe the causal relationship between economic growth and ICT infrastructure.

The first postulates that unidirectional causality flows from ICT infrastructure towards economic growth – the *ICT infrastructure-driven economic growth hypothesis* – and thus that ICT infrastructure contributes to economic growth. The rationale for this argument is that greater investment in ICT infrastructure and subsequent higher adoption of ICT increases labor opportunities and the productivity of firms, which contributes positively to economic growth. Increasing ICT infrastructure also increases jobs and gives birth to new digital industries, which in turn has a positive impact on economic growth. Studies that have explored these relationships include those by Pradhan et al. (2020b), Pradhan et al. (2018), Pradhan et al. (2018), Pradhan et al. (2015), Ghosh (2019, 2016), Arvin and Pradhan (2014), Mehmood and Siddiqui (2013), Gruber and Koutroumpis (2011), Vu (2011), Aker and Mbiti (2010), Laursen and Meliciani (2010), Gholami et al. (2009), Dvornik and Sabolic (2007), Sridhar and Sridhar (2007), Wang and Chien (2007), Carayannis and Popescu (2005), Waverman et al. (2005), and Howells (1995).

The second school of thought posits a unidirectional causality that moves from economic growth towards ICT infrastructure – the *economic growth-driven ICT infrastructure hypothesis* – arguing that economic growth Granger-causes ICT infrastructure. The assumption underpinning this hypothesis is that, as countries increase their economic wealth, they have more resources to improve the existing ICT infrastructure and develop new services that cater to a larger segment of the population and the corporate sector. Studies have also shown that wealthier countries tend to depend more on the digital economy to drive their economic competitiveness, and have therefore intensified the development of more advanced ICT infrastructure. Studies that have explored these relationships include those by Sarangi and Pradhan (2020), Pradhan et al. (2016), Pradhan et al. (2015), Mehmood and Siddiqui (2013), Lee et al. (2012), Lee et al. (2005), Jonathan and Camilo (2008), Dutta (2001), Roller and Waverman (2001), and Capello and Nijkamp (1996).

Based on the discussion above, we test the following hypotheses:

> H_{2A}^{+}: ICT infrastructure (positively) Granger-causes economic growth.

> H_{2B}^{+}: Economic growth (positively) Granger-causes ICT infrastructure.

2.3. Links between financial inclusion and ICT infrastructure

Lastly, we discuss the literature that links financial inclusion and ICT infrastructure. In many developing countries, financial inclusion plans are seen as key development tools to boost the quality of life for vulnerable and marginalized communities. Financial inclusion initiatives include providing these communities with access to much-needed credit, instituting financial literacy programs, and creating other services to boost the economic wealth of members of the community. In many of the localities, especially in rural and remote areas, access to physical financial institutions may be a challenge. Consequently, many people in these communities do not have access to crucial financial services that could improve their lives. To bridge these financial gaps, many countries, including India, have embarked on ambitious financial plans underpinned by an ICT infrastructure plan to deliver financial services to these communities. It is envisaged that digital financial services will enable the large unbanked population to be mainstreamed into the formal financial system, using mobile, internet, and other online banking systems (see Del Gaudio et al., 2020; Senyo and Osabutey, 2020; Siddiqui and Siddiqui, 2020; Lashitew et al., 2019; Berger and Nakata, 2013; Sarma and Pais, 2011; Oyelaran-Oyeyinka and Adeya, 2004). The role of digital financial services in addressing the poverty problem in vulnerable and marginalized communities is summarized in Fig. 3.

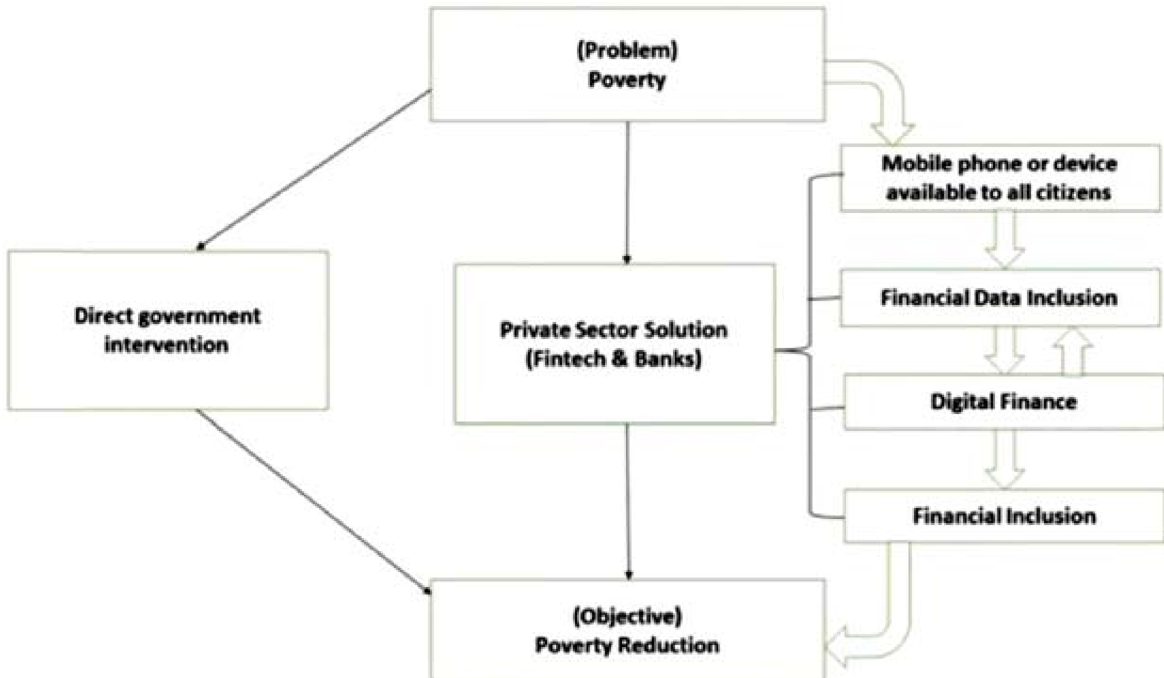


Fig. 3. The analytical framework between financial inclusion and ICT infrastructure **Sources**: Constructed by the authors using analysis in Mushtaq and Bruneaub (2019), Iazzolino (2018), Ozili (2018), and Koker and Jentzsch (2013).

Two schools of thought explain the causal connection between ICT infrastructure and financial inclusion.

The first school assumes a unidirectional causality from ICT infrastructure to financial inclusion, in other words, that ICT infrastructure Granger-causes financial inclusion – the *ICT infrastructure-driven financial inclusion hypothesis*. This hypothesis posits that increasing ICT development will lead to the development of new financial services and applications. These digital financial services enable wider reach by such services and the possibility of customizing services for wider segments of the population. Using digital architecture, financial institutions pursue economies of scale and scope, thus keeping the cost of financial services lower, while also providing a wider range of services. These initiatives should enable marginalized and vulnerable communities to gain better access to these vital financial services. Hence, the development of ICT infrastructure plays a key role in financial inclusion initiatives in many countries. A few recent studies that have examined these relationships include those by Abor et al. (2019), Lashitew et al. (2019), D'Souza (2018), Kim et al. (2018), Pradhan et al. (2018), Pradhan et al. (2018), Ouma et al. (2017), Asongu (2013), and Kpodar and Andrianaivo (2011).

The second school of thought postulates unidirectional causality from financial inclusion toward ICT infrastructure – the *financial inclusion-driven ICT infrastructure hypothesis* – where financial inclusion Granger-causes *ICT infrastructure*. In this case, as marginalized and vulnerable communities gain access to financial services, they have the resources and knowledge to improve their socioeconomic status. Their newfound wealth and knowledge encourage them to acquire new technology such as mobile phones, the internet, and other vital ICT that has the potential to improve their quality of life. This in turn increases the demand for ICT services. Another line of argument to support this direction of the causal relationship is that access to new financial instruments and tools for marginalized and vulnerable communities will result in an increase in infrastructure investments in these localities. These infrastructure investments are important pre-conditions to facilitate a more modern and technology savvy financial system. Hence, an increase in financial inclusion initiatives will increase ICT infrastructure development. Studies that have explored these relationships include those by Chatterjee (2020), Pradhan and Sahoo (2020), Chinoda and Kwenda (2019), Pradhan et al. (2018), and Lenka and Barik (2018).

Based on the discussion above, we test the following hypotheses:

H_{3A}^{+}: ICT infrastructure (positively) Granger-causes financial inclusion.

H_{3B}^{+}: Financial inclusion (positively) Granger-causes ICT infrastructure.

Appendix A, Table A1 presents a summary of the studies in the three strands of literature about the links between financial inclusion, ICT infrastructure, and economic growth.

3. Empirical approach

In the previous section, we have outlined possible causal associations between financial inclusion, ICT infrastructure, and economic development. The hypotheses are graphically summarized in Fig. 4. In this section, we provide a discussion of the empirical method deployed in this research to scrutinize the short-run and long-run dynamics between these variables.

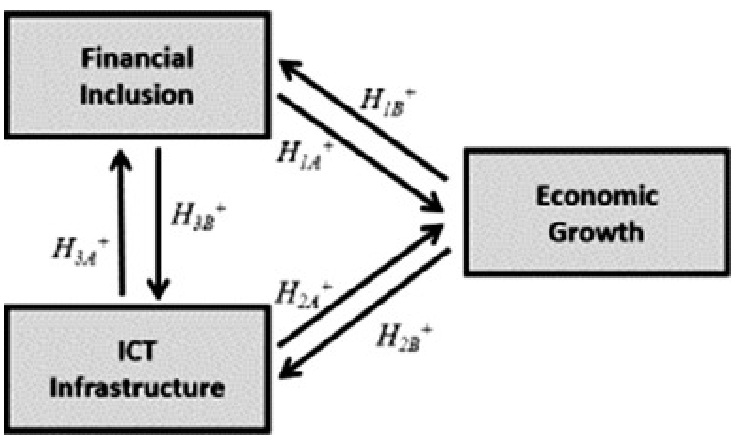


Fig. 4. Possible endogenous links between financial inclusion, ICT infrastructure, and economic growth ***Note:*** "+" denotes a positive causal relationship between the variables. The hypotheses embedded in the directional arrows are discussed in the text.

Our study focuses on 20 Indian states for the period from 1991 to 2018, using annual data procured from the *Indiastat database*, the *RBI database on Indian Economy*, and the *EPWRF database.* The Indian states examined in the study are listed in Appendix B. The choice of India is justified on the ground that it has witnessed the fastest ICT adoption in the world in terms of growing internet and smartphone markets. It is ranked second in terms of number of internet users – i.e., about 462.1 million (Bera, 2019). Additionally, India is second after China in respect of the size of its unbanked population, at about 190 million (see

D'Souza, 2018; Demirgüç-Kunt et al., 2018). The choice of these twenty Indian states was dictated by the availability of data for our chosen variables.

In this study, the percentage change in real per capita state domestic product (PSDP) was used to measure the economic growth rate of the states in India. Three different variables of ICT infrastructure were used, namely telephone landlines (TELE), mobile phone penetration (MOBP), and internet users (INTE). Four different variables of financial inclusion were used, namely banking branch density (BBDE), banking branch penetration (BBPE), loan account penetration (LAPE), and deposit account penetration (DAPE).

Two *composite* indices, namely an ICT infrastructure index (CIIC) and a financial inclusion index (CIFI), were also used to capture the overall status of ICT infrastructure[1] and financial inclusion, respectively. These two indices were used because both financial inclusion and ICT infrastructure are multidimensional phenomena in that they vary in magnitude and time across geographical regions.[2] Hence, we could not fully capture the phenomena if we considered one variable at a time. For example, a region could perform well in one area of a single category (either ICT infrastructure or financial inclusion) but may not perform well in other areas. In this respect, indices can more fully capture the overall ICT infrastructure and the financial inclusion of a state.

Detailed definitions of the indicators are given in Appendix C. Appendix D describes how our *composite* indices (CIIC and CIFI) were constructed using principal component analysis (PCA) (see Tables D1 and D2, respectively). The summary statistics of the variables are supplied in Table 1, and their correlation matrix is reported in Table 2.

Table 1. Descriptive statistics of the variables.

Variables	Descriptive statistics							
	Mean	**Median**	**Maximum**	**Minimum**	**SD**	**SK**	**KU**	**JB**
BBDE	-2.357	-2.376	-1.684	-2.974	0.313	0.053	2.240	6.074*
BBPE	-1.846	-1.767	-1.479	-2.475	0.217	-1.121	3.709	57.13*
LAPE	-1.167	-1.206	-0.421	-1.829	0.253	0.457	3.144	8.839*
DAPE	-0.268	-0.263	0.219	-0.936	0.208	-0.294	3.172	3.889*
CIFI	0.320	0.298	0.707	-0.057	0.155	-0,139	2.853	10.20*
TELE	0.130	0.117	1,070	-1.187	0.585	-0.158	1.865	14.34*
MOBP	-1.167	-1.206	-0.422	-1.829	0.253	0.457	3.144	8.839*
INTE	-4.058	-4.124	-1.395	-6.967	1.024	0.497	3.127	10.36*
CIIC	1.158	1.143	2.106	-0.157	0.586	-0.153	1.864	14.29*
PSDP	4.674	4.689	5.127	4.064	0.209	-0.477	3.184	9.768*

Note 1*:* BBDE: banking branch density; BBPE: banking branch penetration; LAPE: loan account penetration; DAPE: deposit account penetration; CIFI: composite index of financial inclusion; TELE: telephone landlines; MOBP: mobile penetration; INTE: internet users; CIIC: composite index of ICT infrastructure; and PSDP: percentage change in real per capita state domestic product.

Note 2: SD: standard deviation, SK: Skewness; Ku: Kurtosis; and JB: Jarque–Bera statistics.

***Note 3*:** * indicates the probability of significance at the 1% level.

Table 2. Correlation matrix among the variables.

	PSDP	BBDE	BBPE	LAPE	DAPE	CIFI	TELE	MOBP	INTE	CIIC
PSDP	1.000	0.296*	0.268*	0.700*	0.793*	0.271*	0.694*	0.700*	0.433*	0.693
BBDE		1.000	0.242*	-0.061	-0.026	0.842*	-0.011	-0.061	0.155	-0.01
BBPE			1.000	-0.394*	-0.179	0.410*	-0.191	-0.349*	-0.275	-0.19
LAPE				1.000	0.698*	0.225**	0.652*	0.900	0.494	0.651
DAPE					1.000	0.206	0.706*	0.698	0.629*	0.767
CIFI						1.000	0.178	0.225	0.216**	0.179
TELE							1.000	0.652	0.680*	0.999
MOBP								1.0000	0.495*	0.651
INTE									1.0000	0.684
CIIC										1.000

***Note 1**:* BBDE: banking branch density; BBPE: banking branch penetration; LAPE: loan account penetration; DAPE: deposit account penetration; CIFI: composite index of financial inclusion; TELE: telephone landlines; MOBP: mobile penetration; INTE: internet users; CIIC: composite index of ICT infrastructure; and PSDP: percentage change in real per capita state domestic product.

***Note 2*:** * and ** indicate the probability of significance at the 1% and 5% levels, respectively.

This study considered four specifications (expressed in the equations below), each using a different ICT indicator, namely TELE, MOBP, INTE, and CIIC. Furthermore, within each specification, five cases based on the five financial inclusion indicators were used. The variables were transformed into their natural logarithms for the empirical assessment to normalize the data.

The dynamics between economic growth, financial inclusion, and ICT infrastructure are captured by the subsequent dynamic panel set of regression equations:

$$\Delta PSDP_{it} = \alpha_{1j} + \sum_{k=1}^{p} \beta_{1k} \Delta PSDP_{it-k} + \sum_{k=1}^{q} \delta_{1ik} \Delta FINI_{it-k} + \sum_{k=1}^{r} \eta_{1ik} \Delta ICTI_{it-k} + \lambda_{1i} ECT_{it-1} + \xi_{1it} \quad (1)$$

$$\Delta FINI_{it} = \alpha_{2j} + \sum_{k=1}^{p} \beta_{2k} \Delta FINI_{it-k} + \sum_{k=1}^{q} \delta_{2ik} \Delta PSDP_{it-k} + \sum_{k=1}^{r} \eta_{2ik} \Delta ICTI_{it-k} + \lambda_{2i} ECT_{it-1} + \xi_{2it} \quad (2)$$

$$\Delta ICTI_{it} = \alpha_{3j} + \sum_{k=1}^{p} \beta_{3k} \Delta ICTI_{it-k} + \sum_{k=1}^{q} \delta_{3ik} \Delta FINI_{it-k} + \sum_{k=1}^{r} \eta_{3ik} \Delta PSDP_{it-k} + \lambda_{3i} ECT_{it-1} + \xi_{3it} \quad (3)$$

where the first difference operation is denoted as Δ, i is the specific state, t is the year in the panel, and ξ is the random error term. *FINI* is the financial inclusion represented by BBDE, BBPE, LAPE, DAPE, or CIFI, and *ICTI* is the ICT infrastructure signified by TELE, MOBP, INTE, or CIIC.

The terms *p, q*, and *r* denote the lag lengths for these forward-operator variables of the corresponding equations. The optimal lag lengths were determined using the Akaike information criterion and the Schwarz-Bayesian information criterion. The lagged error-correction terms (ECT_{-1}) capture the long-run impact of the three variables. Additionally, the differenced variables determined the short-run relation between the variables.

Short-run causal interactions between these variables are established if the null hypothesis $\delta_{1ik} = 0$ (or $\delta_{2ik} = 0$) is rejected. In this context, this would show that Granger causality runs from FINI to PSDP (or PSDP to FINI). If the null hypothesis $\eta_{1ik} = 0$ (or $\eta_{2ik} = 0$) is rejected, we have Granger causality routed from ICTI to PSDP (or PSDP to ICTI). If the null hypothesis ($\lambda_{1i} = 0$, $\lambda_{2i} = 0$, and $\lambda_{3i} = 0$) is rejected, this indicates the prevalence of long-run associations between these variables. These tests are conducted through a Wald test.

Unit root tests were performed to determine the order of integration of the variables – in other words, to determine whether the data series were stationary or non-stationary. If the data series were resolved to be non-stationary, a cointegration test was conducted to determine the co-moving relationship between these variables. A fully modified ordinary least squares (FMOLS) estimation was also conducted (this is done to determine whether the link is positive or negative) and long-run elasticities were obtained from this estimation. For the short-run relationships, we examined the coefficient of first-difference variables in the estimate equations, Eqs. (1)–(3).

4. Empirical results

In this study, the vector error-correction model (VECM) approach was followed to determine the Granger causal interactions between per capita economic growth, financial inclusion, and ICT infrastructure development. We commenced our empirical examination by obtaining the order of integration of these data series. We then undertook a cointegration analysis to determine the presence or absence of co-moving relationships between these three variables.

4.1. Unit root test and cointegration test results

This study deployed four different panel unit root tests, namely the Levin-Lin-Chu test (LLC), the Im-Pesaran-Shin test (IPS), the PP-Fischer Chi-square test (PP), and the ADF-Fischer Chi-square test (ADF). These tests were used to determine the order of integration of the three data series for the sample countries. The results affirmed that all the variables are integrated of order one, that is I [1] (see Table 3). The empirical analysis shows a strong presence of co-moving associations between the variables under review.

Table 3. Results of panel unit roots test.

Variable	Level	LLC	IPS	ADF	PP	Unit root inferences	
BBDE	0	15.57	16.22	10.51	11.40	1 [1]	
	1	−10.47*	−10.47*	216.4*	226.5*		
BBPE	0	3.842	4.390	24.45	27.04	1 [1]	
	1	−19.25*	−16.25*	324.9*	340.8*		
LAPE	0	4.70	7.49	13.4	13.8	1 [1]	
	1	−20.8*	−18.70*	409.9*	421.7*		
DAPE	0	14.74	18.44	2.73	2.73	1 [1]	
	1	−14.50*	−11.62*	259.9*	260.8*		
	CIFI	0	6.42	9.02	14.46	16.16	1 [1]
1		−22.39*	−19.21*	444.2*	448.7*		
TELE	0	6.298	1.067	34.16	24.08	1 [1]	
		1	−2.61**	−2.012**	46.77*		199.9*
MOBP	0	4.69	7.48	13.47	13.74	1 [1]	
	1	−20.65*	−18.60*	407.4*	419.5*		
INTE	0	−0.37	3.60	14,61	14.46	1 [1]	
	1	−12.92*	−10.31*	189.2*	195.1*		
CIIC	0	4.72	0.94	34.67	94.0	1 [1]	
	1	−3.44*	−9.00*	207.6*	567.6*		
PSDP	0	4.96	11.57	5.96	4.25	1 [1]	
	1	−3.68*	−6.47*	144.5*	505.66*		

Note 1: BBDE: banking branch density; BBPE: banking branch penetration; LAPE: loan account penetration; DAPE: deposit account penetration; CIFI: composite index of financial inclusion; TELE: telephone landlines; MOBP: mobile penetration; INTE: internet users; CIIC: composite index of ICT infrastructure; PSDP: percentage change in real per capita state domestic product.

Note 2: 0 stands for using level data, and 1 stands for using first difference data.

Note 3**:** LLC stands for Levin-Lin-Chu test, IPS stands for Im-Pesaran-Shin test, ADF stands for ADF- Fischer Chi-square test, PP stands for PP-Fischer Chi-square test.

Note 4: * and ** indicate statistical significance at the 1% and 5% levels, respectively. I [1] indicates integration of order one.

The Johansen cointegration test was deployed to test the notion of long-run relationships between the three variables. This test ascertains whether there are long-run equilibrium affiliations between the variables for our four specifications and five cases (see Table 4).

Table 4. Panel cointegration test results.

Specification 1: PSDP, TELE, FINI

Hypothesized No of CE(s)	Case 1 (BBDE) Trace statistic	Case 1 (BBDE) Max-Eigen statistic	Case 2 (BBPE) Trace statistic	Case 2 (BBPE) Max-Eigen statistic	Case 3 (LAPE) Trace statistic	Case 3 (LAPE) Max-Eigen statistic
None	277.5*	247.7*	234.7*	194.8*	223.4*	161.5*
At most 1	83.88*	77.63*	87.03*	86.40*	116.1*	94.15*
At most 2	53.82**	53.82**	78.60*	78.60*	85.83*	85.83*
No of CV(s)		3		3		3

	Case 4 (DAPE) Trace statistic	Case 4 (DAPE) Max-Eigen statistic	Case 5 (CIFI) Trace statistic	Case 5 (CIFI) Max-Eigen statistic
None	216.5*	170.0**	225.8*	182.0**
At most 1	99.51*	85.31*	101.7*	88.18*
At most 2	73.12*	73.12*	74.12*	74.12*
No of CV(s)		3		3

Specification 2: PSDP, MOBP, FINI

Hypothesized No of CE(s)	Case 1 (BBDE) Trace statistic	Case 1 (BBDE) Max-Eigen statistic	Case 2 (BBPE) Trace statistic	Case 2 (BBPE) Max-Eigen statistic	Case 3 (LAPE) Trace statistic	Case 3 (LAPE) Max-Eigen statistic
None	224.4*	182.5*	227.0*	183.6*	118.7*	100.2*
At most 1	102.2*	99.77*	97.55*	95.42*	58.76	55.45
At most 2	81.65*	81.65*	42.54	42.54	54.44	54.44
No of CV(s)		3		2		1

	Case 4 (DAPE) Trace statistic	Case 4 (DAPE) Max-Eigen statistic	Case 5 (CIFI) Trace statistic	Case 5 (CIFI) Max-Eigen statistic
None	219.7*	180.4*	260.7*	214.9*
At most 1	100.6*	99.62*	114.2*	104.2*
At most 2	51.73	51.73	68.66	68.66
No of CV(s)		2		2

Specification 3: PSDP, INTE, FINI

Hypothesized No of CE(s)	Case 1 (BBDE) Trace statistic	Case 1 (BBDE) Max-Eigen statistic	Case 2 (BBPE) Trace statistic	Case 2 (BBPE) Max-Eigen statistic	Case 3 (LAPE) Trace statistic	Case 3 (LAPE) Max-Eigen statistic
None	212.7*	156.3*	207.0*	165.9*	233.6*	179.7*
At most 1	100.4*	93.01*	82.42*	71.44*	95.26*	92.06*
At most 2	76.7*	76.70*	48.63**	48.63**	33.77	33.77
No of CV(s)		3		3		3

	Case 4 (DAPE)		Case 5 (CIFI)	
	Trace statistic	Max-Eigen statistic	Trace statistic	Max-Eigen statistic
None	179.0*	147.1*	187.2*	147.8*
At most 1	71.60*	71.76*	81.46*	71.30*
At most 2	28.04	28.04	43.17***	43.17***
No of CV(s)		2		3

Specification 4: PSDP, CIIC, FINI

	Case 1 (BBDE)		Case 2 (BBPE)		Case 3 (LAPE)	
Hypothesized No of CE(s)	Trace statistic	Max-Eigen statistic	Trace statistic	Max-Eigen statistic	Trace statistic	Max-Eigen statistic
None	276.4*	212.7*	294.1*	220.2*	277.3 *	217.3*
At most 1	122.9*	105.9*	137.3*	120.5*	127.7*	117.2*
At most 2	75.16*	75.16*	72.5*	72.5*	65.7	65.7
No of CV(s)		3		3		2

	Case 4 (DAPE)		Case 5 (CIFI)	
	Trace statistic	Max-Eigen statistic	Trace statistic	Max-Eigen statistic
None	297.0*	228.2*	355.1*	271.7*
At most 1	138.4*	141.2*	160.0*	150.3*
At most 2	47.58***	47.58***	67.48***	67.48***
No of CV(s)		3		3

Note 1: BBDE: banking branch density; BBPE: banking branch penetration; LAPE: loan account penetration; DAPE: deposit account penetration; CIFI: composite index of financial inclusion; TELE: telephone landlines; MOBP: mobile penetration; INTE: internet users; CIIC: composite index of ICT infrastructure; and PSDP: percentage change in real per capita state domestic product.

Note 2: Case 1 is cointegration between PSDP, ICTI, and BBDE. Case 2 is cointegration between PSDP, ICTI, and BBPE. Case 3 is cointegration between PSDP, ICTI, and LAPE. Case 4 is cointegration between PSDP, ICT, and DAPE. And Case 5 is cointegration between PSDP, ICTI, and CIFI.

Note 3: *, **, and *** indicate the probability of significance at the 1%, 5%, and 10% levels, respectively.

4.2. FMOLS results

Since there was a prevalence of cointegration relationships between the variables, the FMOLS method was used to determine the sign of the long-run dynamics between these variables. The estimated results from the FMOLS technique for all five cases under Specifications 1 to 4 are set out in Table 5. The results show that there is a significant positive association between the per capita state domestic product and financial inclusion. Similar results pertain to the relationship between ICT and PSDP. This implies that ICT infrastructure development has a significant positive influence on PSDP. These results suggest the existence of robust inter-relationships between these three variables. The direction of the underlying ties between these variables in the short run and the long run is determined through the analysis discussed in the next section.

Table 5. FMOLS estimates.

Independent variables	Cases		
Specification 1: PSDP, TELE, FINI			
	Case 1 (BBDE)	**Case 2 (BBPE)**	**Case 3 (LAPE)**
PSDP	0.269/ 7.739*	0.128/ 2.169**	0.377/ 30.56*
FINI	0.463/ 6.810*	0.234/ 2.560*	0.341/ 27.38*
	Case 4 (DAPE)	**Case 5 (CIFI)**	
PSDP	0.125/ 23.04*	0.131/ 2.897*	
FINI	0.756/ 23.47*	0.277/ 4.228*	
Specification 2: PSDP, MOBP, FINI			
	Case 1 (BBDE)	**Case 2 (BBPE)**	**Case 3 (LAPE)**
PSDP	0.023/ 3.532*	0.016/ 2.075**	0.037/ 2.214**
FINI	0.454/ 30.21*	0.700/ 35.78**	0.998/ 5.502*
	Case 4 (DAPE)	**Case 5 (CIFI)**	
PSDP	0.327/ 7.524*	0.299/ 13.07*	
FINI	0.377/ 11.33*	0.916/ 27.58*	
Specification 3: PSDP, INTE, FINI			
	Case 1 (BBDE)	**Case 2 (BBPE)**	**Case 3 (LAPE)**
PSDP	0.579/ 10.55*	0.731/ 17.66*	0.153/ 5.335*
FINI	0.352/ 3.638*	0.606/ 6.903*	0.268/ 23.41*
	Case 4 (DAPE)	**Case 5 (CIFI)**	
PSDP	0.656/ 29.79*	0.901/ 27.59*	
FINI	0.305/ 11.18*	0.206/ 4.957*	
Specification 4: PSDP, CIIC, FINI			
	Case 1 (BBDE)	**Case 2 (BBPE)**	**Case 3 (LAPE)**
PSDP	0.737/ 4.478*	0.451/ 3.252*	0.269/ 4.372*
FINI	0.436/ 4.532*	0.935/ 3.332*	0.977/ 5.372*
	Case 4 (DAPE)	**Case 5 (CIFI)**	
PSDP	0.523/ 4.220*	0.444/ 9.945*	
FINI	0.942/ 10.13*	0.900/ 19.53*	

***Note 1**:* BBDE: banking branch density; BBPE: banking branch penetration; LAPE: loan account penetration; DAPE: deposit account penetration; CIFI: composite index of financial inclusion; TELE: telephone landlines; MOBP: mobile penetration; INTE: internet users; CIIC: composite index of ICT infrastructure; PSDP: percentage change in real per capita state domestic product.

***Note 2**:* FINI is used for BBDE, BBPE, LAPE, DAPE, and CIFI.

Note 3**:** * and ** indicate the probability of significance at the 1% and 5% levels, respectively.

4.3. Granger causality results

The findings from the cointegration analysis and FMOLS estimation show that VECM is the most appropriate method to ascertain the potential Granger causal associations between financial inclusion, ICT infrastructure, and PSDP. The results are set out in Table 6. We highlight here the long-run and short-run dynamics.

Table 6. Empirical results of panel Granger causality test.

Dependent variable	Independent variables and ECT_{-1}

Specification 1: PSDP, TELE, FINI

	Case 1 (BBDE)			
	ΔPSDP	ΔTELE	ΔBBDE	ECT_{-1}
ΔPSDP	-------	5.22**	6.44**	-0.001
ΔTELE	1.29	-------	5.24**	-0.019*
ΔFINI	0.69	4.97***	-------	-0.004

	Case 2 (BBPE)			
	ΔPSDP	ΔTELE	ΔBBPE	ECT_{-1}
ΔPSDP	-------	4.86***	24.1*	-0.004
ΔTELE	0.47	-------	24.4*	-0.012*
ΔFINI	6.39*	10.41*	-------	-0.001

	Case 3 (LAPE)			
	ΔPSDP	ΔTELE	ΔLAPE	ECT_{-1}
ΔPSDP	-------	4.19***	5.88**	-0.001
ΔTELE	3.64	-------	17.98*	-0.015*
ΔFINI	0.64	9.57*	-------	-0.005

	Case 4 (DAPE)			
	ΔPSDP	ΔTELE	ΔDAPE	ECT_{-1}
ΔPSDP	-------	4.43***	8.58*	-0.001
ΔTELE	0.21	-------	16.30*	-0.015*
ΔFINI	2.33	9.42*	-------	-0.005

	Case 5 (CIFI)			
	ΔPSDP	ΔTELE	ΔCIFI	ECT_{-1}
ΔPSDP	-------	4.36***	20.99*	-0.001
ΔTELE	0.78	-------	13.18*	-0.019*
ΔFINI	9.72*	4.56***	-------	-0.002

Specification 2: PSDP, MOBP, FINI

	Case 1 (BBDE)			
	ΔPSDP	ΔMOBP	ΔBBDE	ECT_{-1}
ΔPSDP	-------	12.57*	4.01***	-0.007
Δ MOBP	1.66	-------	4.69***	-0.029*
ΔFINI	0.83	5.66**	-------	-0.039

	Case 2 (BBPE)			
	ΔPSDP	Δ MOBP	ΔBBPE	ECT_{-1}
ΔPSDP	-------	7.80*	4.63***	-0.005
Δ MOBP	2.38	-------	6.65**	-0.029*
ΔFINI	1.56	11.94*	-------	-0.045

	Case 3 (LAPE)			
	ΔPSDP	Δ MOBP	ΔLAPE	ECT_{-1}
ΔPSDP	-------	4.89***	4.20***	-0.001
Δ MOBP	0.184	-------	5.91**	-0.015*
ΔFINI	0.73	4.20***	-------	-0.001

	Case 4 (DAPE)			
	ΔPSDP	Δ MOBP	ΔDAPE	ECT_{-1}
ΔPSDP	-------	4.97***	6.88**	-0.002
Δ MOBP	3.41	-------	3.88***	-0.009*
ΔFINI	3.98***	8.91* -	------	-0.003

	Case 5 (CIFI)			
	ΔPSDP	Δ MOBP	ΔCIFI	ECT_{-1}
ΔPSDP	-------	5.61**	7.35*	-0.002
Δ MOBP	3.461	-------	5.22**	-0.026*
ΔFINI	5.49**	4.82***	-------	-0.034

Specification 3: PSDP, INTE, FINI

Case 1 (BBDE)

	ΔPSDP	ΔINTE	ΔBBDE	ECT_{-1}
ΔPSDP	-------	12.57*	6.22*	-0.002
Δ INTE	4.99***	-------	5.49*	-0.025*
ΔFINI	7.18*	3.53***	-------	-0.009

Case 2 (BBPE)

	ΔPSDP	ΔINTE	ΔBBPE	ECT_{-1}
ΔPSDP	-------	9.88*	2.75	-0.002
Δ INTE	4.92***	-------	7.67**	-0.010*
ΔFINI	8.25*	21.1*	-------	-0.002

Case 3 (LAPE)

	ΔPSDP	ΔINTE	ΔLAPE	ECT_{-1}
ΔPSDP	-------	10.29*	2.14	-0.001
Δ INTE	9.52*	-------	10.37*	-0.029*
ΔFINI	4.31***	37.6*	-------	-0.026

Case 4 (DAPE)

	ΔPSDP	ΔINTE	ΔDAPE	ECT_{-1}
ΔPSDP	-------	6.39**	2.57	-0.002
Δ INTE	5.75**	-------	24.7*	-0.003*
ΔFINI	11.4*	18.1*	-------	-0.037

Case 5 (CIFI)

	ΔPSDP	ΔINTE	ΔCIFI	ECT_{-1}
ΔPSDP	-------	9.81*	1.62	-0.002
Δ INTE	6.93*	-------	4.95***	-0.050*
ΔFINI	7.13*	23.2*	-------	-0.007

Specification 4: PSDP, CIIC, FINI

Case 1 (BBDE)

	ΔPSDP	ΔCIIC	ΔBBDE	ECT_{-1}
ΔPSDP	-------	10.53*	7.23*	-0.007
Δ CIIC	3.28	-------	4.02***	-0.674*
ΔFINI	1.72	5.66*	-------	-0.017

Case 2 (BBPE)

	ΔPSDP	ΔCIIC	ΔBBPE	ECT_{-1}
ΔPSDP	-------	9.15*	10.2*	-0.004
Δ CIIC	3.46	-------	4.24***	-0.565*
ΔFINI	4.54***	50.4*	-------	-0.017

Case 3 (LAPE)

	ΔPSDP	ΔCIIC	ΔLAPE	ECT_{-1}
ΔPSDP	-------	12.45*	9.67*	-0.002
ΔCIIC	1.01	-------	7.28*	-0.677*
ΔFINI	1.53	24.3*	-------	-0.028

Case 4 (DAPE)

	ΔPSDP	ΔCIIC	ΔDAPE	ECT_{-1}
ΔPSDP	-------	6.17*	8.23*	-0.006
ΔCIIC	1.40	-------	26.01*	-0.657*
ΔFINI	0.40	54.90*	-------	-0.028

Case 5 (CIFI)

	ΔPSDP	ΔCIIC	ΔCIFI	ECT_{-1}
ΔPSDP	-------	10.98*	6.30*	-0.003
ΔCIIC	0.70	-------	11.23*	-0.427*
ΔFINI	2.50	40.7*	-------	-0.013

***Note 1**:* BBDE: banking branch density; BBPE: banking branch penetration; LAPE: loan account penetration; DAPE: deposit account penetration; CIFI: composite index of financial inclusion; TELE: telephone landlines; MOBP: mobile penetration; INTE: internet users; CIIC: composite index of ICT infrastructure; PSDP: percentage change in real per capita state domestic product; ECT_{-1}: lagged error-correction term.

***Note 2**:* FINI is used for BBDE, BBPE, LAPE, DAPE, and CIFI.

***Note 3*:** *, **, and *** indicate the probability of significance at the 1%, 5%, and 10% levels, respectively.

4.3.1. Long-run dynamic results

The coefficients for the ECT_{-1} terms are statistically significant at the 1% level when the dependent variable is ΔICTI. This suggests that both PSDP and financial inclusion have a significant impact on ICT infrastructure in the long term. Additionally, the coefficient of the ECT_{-1} terms are negative. This suggests that shocks to economic growth, along with financial inclusion variables, cause the ICT infrastructure variable to adjust back completely to the long-run equilibrium path. The convergence back to the long-term equilibrium path varies; it is dependent on the different specifications and cases. For Specification 1, it varies from 1.2% in Case 2 to 1.9% in Case 5. For Specification 2, it varies from 0.9% in Case 4 to 2.5% in Case 5. For Specification 3, it varies from 0.03% in Case 4 to 0.50% in Case 5. For Specification 4, it varies from 43% in Case 5 to 68% in Case 3 (see estimates of ECT coefficients in Table 6). In conclusion, we have support for all four of our specifications and 20 cases for H_{2B}^{+} and H_{3B}^{+}.

There are some unexpected results, however, based on the statistical insignificance of the remaining lagged ECT coefficients: there is no long-run causality that flows from ICT infrastructure and financial inclusion to economic growth. Furthermore, there is no interconnection from ICT infrastructure and economic growth to financial inclusion in the long run. However, as indicated below, these results do not carry over to the short run.

4.3.2. Short-run dynamic results

In reaction to long-run dynamics, the short-run associations between these three variables vary, based on the choice of variables used in the models. An abstract of the short-run Granger interconnection results is provided in Table 7. The results show that the short-run fine-tuning dynamics diverge across the four specifications and the five cases in each specification. With regard to the relationship between economic growth plus ICT infrastructure, 15 out of 20 cases (BBDE, BBPE, LAPE, DAPE, and CIFI for Specification 1; BBDE, BBPE, LAPE, DAPE, and CIFI for Specification 2; and BBDE, BBPE, LAPE, DAPE, and CIFI for Specification 4) support the *ICT infrastructure-driven economic growth hypothesis* (H_{2A}^{+}). The remaining five cases for Specification 3 support the *feedback hypothesis* between economic growth and ICT infrastructure. These results suggest a strong indication that ICT infrastructure in Indian states contributes to economic growth in the short run.

Table 7. Summary of short-run Granger causality results.

Specification	Case	Possible direction of causality between the variables		
		PSDP and FINI	**PSDP and ICTI**	**FINI and ICTI**
	1	PSDP ← BBDE	PSDP ← TELE	BBDE ↔ TELE
1	2	PSDP ↔ BBPE	PSDP ← TELE	BBPE ↔ TELE
	3	PSDP ← LAPE	PSDP ← TELE	LAPE ↔ TELE
	4	PSDP ← DAPE	PSDP ← TELE	DAPE ↔ TELE
	5	PSDP ↔ CIFI	PSDP ← TELE	CIFI ↔ TELE
	1	PSDP ← BBDE	PSDP ← MOBP	BBDE ↔ MOBP
2	2	PSDP ← BBPE	PSDP ← MOBP	BBPE ↔ MOBP
	3	PSDP ← LAPE	PSDP ← MOBP	LAPE ↔ MOBP
	4	PSDP ↔ DAPE	PSDP ← MOBP	DAPE ↔ MOBP
	5	PSDP ↔ CIFI	PSDP ← MOBP	CIFI ↔ MOBP
	1	PSDP ↔ BBDE	PSDP ↔ INTE	BBDE ↔ INTE
3	2	PSDP → BBPE	PSDP ↔ INTE	BBPE ↔ INTE
	3	PSDP → LAPE	PSDP ↔ INTE	LAPE ↔ INTE
	4	PSDP → DAPE	PSDP ↔ INTE	DAPE ↔ INTE
	5	PSDP → CIFI	PSDP ↔ INTE	CIFI ↔ INTE
	1	PSDP ← BBDE	PSDP ← CIIC	BBDE ↔ CIIC
4	2	PSDP ↔ BBPE	PSDP ← CIIC	BBPE ↔ CIIC
	3	PSDP ← LAPE	PSDP ← CIIC	LAPE ↔ CIIC
	4	PSDP ← DAPE	PSDP ← CIIC	DAPE ↔ CIIC
	5	PSDP ← CIFI	PSDP ← CIIC	CIFI ↔ CIIC

Note 1*:* BBDE: banking branch density; BBPE: banking branch penetration; LAPE: loan account penetration; DAPE: deposit account penetration; CIFI: composite index of financial inclusion; TELE: telephone landlines; MOBP: mobile penetration; INTE: internet users; CIIC: composite index of ICT infrastructure; PSDP: percentage change in real per capita state domestic product.

Note 2*:* FINI is used for BBDE, BBPE, LAPE, DAPE, and CIFI, while ICTI is used for TELE, MOBP, INTE, and CIIC.

Note 3: ←/ →/↔ indicate the direction of Granger causality.

In respect of the economic growth-financial inclusion relationship, 10 out of 20 cases back the *financial inclusion-driven economic growth hypothesis* (H_{1A}^{+}), 4 out of 20 cases support the *economic growth-driven financial inclusion growth hypothesis* (H_{1B}^{+}), while the remaining cases support the *feedback hypotheses*. In all these cases, the causal relationships are significant. The dynamic relationship discussed above provides a strong signal that financial inclusion is critical for India's economic growth. The empirical analysis also shows that an escalation in economic growth has an underlying impact on financial inclusion in these states' economies. One of the interesting features is that the direction of causality between financial inclusion and economic growth depends on the financial inclusion variables used in the model. When branch density is used, the causal relationship is primarily from financial inclusion to economic growth. In the case of bank branch penetration, however, the direction of causality is either reversed or bidirectional. Out of 4 cases, only one shows a direction of causality from bank branch penetration rate to economic growth. This suggests that economic growth in several of these states encourages financial inclusion (banking branch penetration rate) – which is a good signal in that increasing wealth is enabling marginalized communities to have access to financial services via an online platform, which is considerably cheaper than physical banks or branches.

The setting of the ICT infrastructure–financial inclusion relationship shows that 20 of 20 cases support the *feedback hypothesis*. In other words, financial inclusion has a significant influence on ICT infrastructure, and ICT infrastructure also has a significant influence on financial inclusion.

4.4. Robustness test results

In this study, we also undertook four further analyses to validate the results obtained in the previous section. First, a dynamic ordinary least squares (DOLS) estimation was conducted and the estimated results show that financial inclusion, ICT infrastructure, and economic growth are related. The results are consistent with those of studies such as the ones by Chatterjee (2020), Kim et al. (2018), Pradhan et al. (2018), Pradhan et al. (2015), Laursen and Meliciani (2010), Wang and Chien (2007), Hyytinen and Toivanen (2005), Carayannis and Popescu (2005), and Oyelaran-Oyeyinka and Adeya (2004). The results for the DOLS are not conveyed in this paper due to space limitations, but the results can be obtained from the authors.

Second, to assess the robustness of the results, the order of the VECM was changed in the estimation. The empirical results show that there are no substantial changes between the estimated results and the ones described in Table 6. Due to space limitations, the results are not given here, but can be requested from the authors.

Third, we performed a region-wise analysis for the northern, southern, eastern, and western states separately. These findings are more or less the same as the results from the combined sample of 20 Indian states. In the interest of saving space, the results are not given here, but can be obtained from the authors.

Fourth, the generalized forecast error variance decomposition technique was used to test the robustness of the dynamic affiliation between economic growth, financial inclusion, and ICT infrastructure development. This approach shows the trend of ICT infrastructure when various degrees of shocks occurred for economic growth and financial inclusion initiatives. The results confirm that economic growth and financial inclusion will continue to influence ICT infrastructure development in the long run for these Indian states. The results of this analysis can be obtained from the authors.

5. Policy implications and conclusions

This study investigated the short-term and the long-term interfaces between economic growth, financial inclusion, and ICT infrastructure in a sample of 20 Indian states. Our fundamental contribution is melding three threads of literature to *simultaneously* examine the association between all three variables, all in the context of one of the most important emerging economies.

The empirical results show that there are strong endogenous associations between these three sets of variables in the short and long term. The short-run analysis indicates that economic growth, financial inclusion, and ICT infrastructure development in the Indian states are strongly interdependent. Therefore, an increase in financial inclusion initiatives and ICT infrastructure investment will contribute to economic development. Strong economic development in these states will also contribute to an increase in financial inclusion initiatives and investments in ICT infrastructure. The empirical results also show a strong interdependence between ICT infrastructure development and financial inclusion programs. In the long term, the results show that strong economic growth plus financial inclusion initiatives will contribute significantly to ICT infrastructure development in the Indian states.

The strong endogenous association between economic growth strategies, financial inclusion initiatives, and ICT infrastructure development plans suggests that sustainable economic development of the Indian states depends on the formulation of an integrated policy framework that deepens the impact of each of the variables on the others. In this context, it should be noted that although ICT infrastructure development, especially the adoption of mobile phones and the internet in many Indian states, has intensified, the number of people gaining access to financial services in some of these states has not kept pace with the digitization of the economy.

The slow adoption of ICT and financial services among a large percentage of the population in several Indian states has kept wealth accumulation relatively low, compared to that in states which have access to financial systems underpinned by strong ICT infrastructure. The differences between the various Indian states can be attributed to several factors, including the following: poor infrastructure transportation systems (in the Himalayan and eastern states of India), weak ICT infrastructure, low literacy levels, cultural barriers, low participation by women in the labor market, and a large percentage of the population who do not have proper identification documents, who live below the poverty line, and who are employed in the informal sector (Ravi, 2019). The issue of informal employment is one of the key reasons that many do not have any route into formal financial and banking services – a large part of the population operates in a cash economy, and many rely on their family members, friends, and other financial intermediaries to sustain their daily livelihood.

To close the wealth gap between the different states in India, the federal and state governments need to partner with key stakeholders to ensure that co-development policies are put in place to increase the use of digital financial systems that spur economic growth in these states. The wealth generated should be used to intensify the ICT infrastructure that supports a modern and advanced financial system that caters to the needs of a wider segment of the population, especially those living in rural and remote areas. This new modern financial architecture should also enable segments of the population that have so far been excluded from the economy to gain access to financial services and to improve their quality of life. This includes undertaking the following reforms in the ICT and financial ecosystems and reinforcing economic growth (see Ajide et al., 2020; Bill and Melissa Gates Foundation, 2020, 2019; Del Gaudio et al., 2020; Reserve Bank of India, 2020; Senyo and Osabutey, 2020; Siddiqui and Siddiqui, 2020; Lashitew et al., 2019; USAID, 2019; Demirgüç-Kunt et al., 2018; Pandey and Banwet, 2018; Klapper and Hess, 2016; and Berger and Nakata, 2013):

- Intensify ICT infrastructure development across the country, especially in rural and remote areas, which includes resolving the "last-mile" problem – connecting villages to main ICT infrastructure that provides access to financial services and other economic opportunities for disadvantaged communities. Hence, investments in ICT infrastructure in the marginalized areas will go a long way to promote the penetration of regional finance and enhance financial inclusion in India.

- Improve the interoperability of payment systems among diverse providers of financial services so that access to these services is provided, irrespective of the service providers.
- Ensure that a secure digital identification system is in place, using the current Aadhar system in India and combining it with more advanced biometric and digital identification systems (fingerprinting or iris scanning) to enable access to secure financial services and economic opportunities for the people.
- Use the ICT infrastructure to roll out advanced, safe, efficient, useful user-friendly and cost-effective digital financial payment systems, using the personal identification system mentioned above, including fintech and blockchain to deliver financial inclusion programs.
- Develop user-friendly digital financial applications in languages suited to the diverse populations and intensify digital financial literacy programs, especially in disadvantaged, rural, and remote communities.
- Government services should transition towards the use of user-friendly digital financial systems for tax collection, the payment of subsidies, and other cash transfer programs for poor and rural communities, with good "handholding" measures in place to increase the take-up the digital financial services.
- Ensure that the regulatory reforms of the financial sector keep pace with technological developments to ensure that cyber-crime, fraud, and other market failures do not undermine consumer confidence in the use of digital financial platforms, especially in vulnerable segments of the population.
- Intensify gender and vulnerable group-specific digital financial inclusion initiatives to increase the use of these programs among these segments of the population. The key initiatives should include nurturing and supporting community champions and peer groups to encourage, educate, and inspire them to participate in the digital economy, and thus transcending traditional Indian socio-cultural norms.

The discussions above highlight that, while there are challenges in locating financial institutions and creating vibrant economic ecosystems in several regions in India, the digitization of the economy will enable many of these states to overcome these challenges by providing digital financial services. Access to these financial services will be critical for stimulating economic development in this region.

In summary, our paper shows that policymakers in India should give careful attention to co-development policy initiatives pertaining to ICT infrastructure development, financial inclusion initiatives, and economic growth-promoting policies to ensure sustainable economic development in the various states in India. The result for the Indian case study may be useful for other developing countries' plans to bridge digital, financial, and wealth gaps in their countries.

Declaration of Competing Interest

None.

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Appendix A. Summary of literature

Table A1. Review of studies that suggest causal dynamics between financial inclusion, ICT infrastructure, and economic growth.

Studies	***Sample***	***Period***	***Validity of Hypotheses***
Case 1: Studies between financial inclusion and economic growth			
Pradhan, Arvin et al. (2018)	G-20 countries	1990–2014	$H^{A}_{1}{}^{+}$, $H^{A}_{2}{}^{+}$
Sethi and Acharya (2018)	31 countries	2004–2010	$H^{A}_{1}{}^{+}$
Gul et al. (2018)	185 countries	1996–2018	$H^{A}_{1}{}^{+}$, $H^{A}_{2}{}^{+}$
Klein and Olivei (2008)	Various countries	1976–1995	$H^{A}_{1}{}^{+}$
Lenka and Sharma (2017)	India	1980–2014	$H^{A}_{1}{}^{+}$
Sharma and Bardhan (2017)	India	1980–2011	$H^{A}_{1}{}^{+}$, $H^{A}_{2}{}^{+}$
Pradhan and Arvin (2016)	21 Asian countries	1961–2012	$H^{A}_{1}{}^{+}$, $H^{A}_{2}{}^{+}$
Pradhan, Arvin, Norman, and Bennett (2016)	Next 11countries	2001–2012	$H^{A}_{1}{}^{+}$, $H^{A}_{2}{}^{+}$
Case 2: Studies between ICT infrastructure and economic growth			
Pradhan, Arvin et al. (2018)	G-20 countries	1990–2014	$H^{B}_{1}{}^{+}$, $H^{B}_{2}{}^{+}$
Pradhan and Arvin (2016)	21 Asian countries	1961–2012	$H^{B}_{1}{}^{+}$, $H^{B}_{2}{}^{+}$
Pradhan, Arvin, Norman, and Bennett (2016)	Next 11countries	2001–2012	$H^{B}_{1}{}^{+}$, $H^{B}_{2}{}^{+}$
Pradhan et al. (2013)	OECD countries	1961–2011	$H^{B}_{1}{}^{+}$, $H^{B}_{2}{}^{+}$
Mehmood and Siddiqui (2013)	23 ACs	1990–2010	$H^{B}_{1}{}^{+}$
Lee et al. (2012)	3 NACs	1975–2009	$H^{B}_{2}{}^{+}$
Shiu and Lam (2008)	China	1978–2004	$H^{B}_{1}{}^{+}$, $H^{B}_{2}{}^{+}$
Beil et al. (2005)	USA	1947–1996	$H^{B}_{2}{}^{+}$
Cieślik and Kaniewsk (2004)	Poland	1989–1998	$H^{B}_{1}{}^{+}$
Case 3: Studies between financial inclusion and ICT infrastructure			
Pradhan, Arvin et al. (2018)	G-20 countries	1990–2014	$H^{C}_{1}{}^{+}$, $H^{C}_{2}{}^{+}$
Lenka and Barik (2018)	SAARC countries	2004–2014	$H^{C}_{1}{}^{+}$
Pradhan and Arvin (2016)	21 Asian countries	1961–2012	$H^{C}_{1}{}^{+}$, $H^{C}_{2}{}^{+}$
Ghosh (2016)	India	1997–2010	$H^{C}_{1}{}^{+}$, $H^{C}_{2}{}^{+}$
Chinoda and Kwenda (2019)	49 countries	2004–2016	$H^{C}_{1}{}^{+}$
Andrianaivo and Kpodar (2012)	African countries	1988–2007	$H^{C}_{2}{}^{+}$

***Note 1*:** $H^{A}_{1}{}^{+}$ is a supply-leading hypothesis, representing causality from financial inclusion to economic growth. $H^{A}_{2}{}^{+}$ is a demand-following hypothesis, representing causality from economic growth to financial inclusion. $H^{B}_{1}{}^{+}$ is a supply-leading hypothesis, representing causality from ICT infrastructure to economic growth. $H^{B}_{2}{}^{+}$ is a demand-following hypothesis, representing causality from economic growth to ICT infrastructure. $H^{C}_{1}{}^{+}$ is a supply-leading hypothesis, representing causality from ICT infrastructure to financial inclusion. And $H^{C}_{2}{}^{+}$ is a demand-following hypothesis, representing causality from financial inclusion to ICT infrastructure.

Note 2: ICT infrastructure is used for telephone landlines, mobile phones, and internet users.

Note 3: Financial inclusion is considered here as the use of banking branch density, banking branch penetration, loan account penetration, and deposit account penetration.

Appendix B. Sample states

Our sample covers 20 Indian states: Andhra Pradesh, Assam, Bihar, Chhattisgarh, Gujarat, Haryana, Himachal Pradesh, Jammu and Kashmir, Jharkhand, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Odisha, Punjab, Rajasthan, Tamil Nadu, Uttarakhand, Uttar Pradesh, and West Bengal. The empirical analysis is based on a panel data analysis of 20 Indian states. We also have a few sub-samples regarding the geographical location of states and states' level of economic development. These include the *northern, southern, western*, and *eastern* parts of India. *Northern India* includes Punjab, Uttar Pradesh, Rajasthan, Haryana, and Himachal Pradesh. *Southern India* includes Andhra Pradesh, Tamil Nadu, Karnataka, and Kerala. *Western India* includes Goa, Gujarat, Maharashtra, and Madhya Pradesh. *Eastern India* includes Arunachal Pradesh, Assam, Manipur, Meghalaya, Tripura, Odisha, Bihar, and West Bengal. The map below provides an overview of the regional classification of Indian states (Fig. B1).

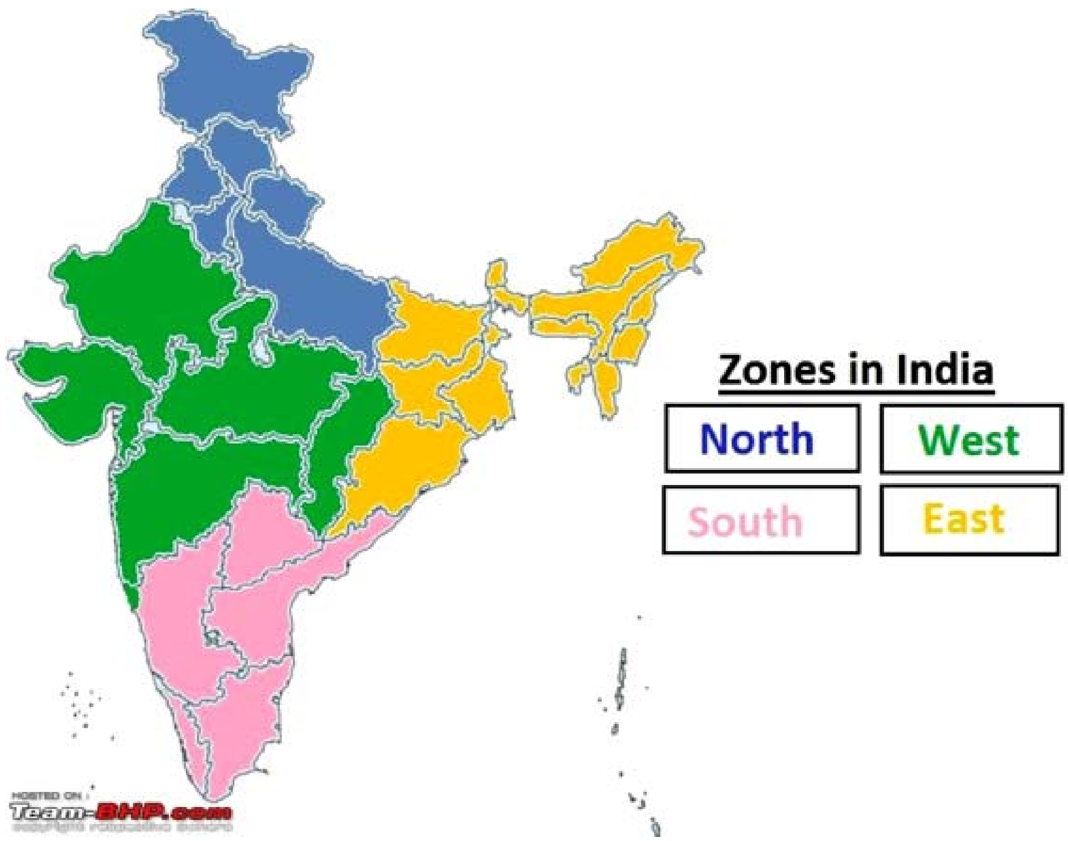

Fig. B1. Region-wise classification of states of India Source: https://www.team-bhp.com.

Appendix C. Definition of variables

Table C1. Definition of variables.

Variable acronym	***Variable definition***
PSDP	Percentage change in real per capita state domestic product – used to measure the economic growth rate of a state in India
BBDE	Banking branch density, measured as the total number of bank branches per square kilometer
BBPE	Banking branch penetration, measured as the total number of bank branches per population
LAPE	Loan account penetration, measured as the total number of loan accounts per population
DAPE	Deposit account penetration, measured as the total number of deposit accounts per population
CIFI	Composite index of financial inclusion, using BBDE, BBPE, LAPE, and DAPE – derived from principal component analysis
TELE	Telephone landlines, measured as total telephone landlines per thousand of population
MOBP	Mobile penetration, measured as total mobile phone subscribers per thousand of population
INTE	Internet users, measured as total internet users per thousand of population
CIIC	Composite index of ICT infrastructure, using TELE, MOBP, and INTE – derived from principal component analysis

Note: These variables are defined more comprehensively in the data sources identified in the text. Monetary variables are expressed in real terms.

Appendix D. Construction of composite indices of financial inclusion and ICT infrastructure using PCA

We built composite indices of financial inclusion and ICT infrastructure, henceforth symbolized by CIFI and CIIC respectively. The two indices were developed through principal component analysis (PCA). The process is outlined in most textbooks and is used in numerous research papers, including ones by Yorulmaz (2018) and Pradhan et al. (2018). Thus, it is not described here. The variables included for CIFI are BBDE, BBPE, LAPE, and DAPE, while the variables included for CIIC are TELE, MOBP, and INTE. Tables D1 and D2 supply statistical information from our PCA,[3] while Fig. D1, Fig. D2 present the variable loading plots from our PCA for the two composite indices.

Table D1. PCA-related evidence for deriving the financial inclusion index.

Part A: Eigen analysis of correlation matrix				
PC	**Eigen value**	**Proportion**	**Cumulative value**	**Cumulative proportion**
1	2.457	0.614	2.457	0.614
2	0.878	0.219	3.335	0.834
3	0.554	0.139	3.889	0.972
4	0.111	0.028	4.000	1.000
Part B: Eigen vectors (component loadings)				
Variable	**PC1**	**PC2**	**PC3**	**PC4**
BBDE	0.328	0.863	0.384	0.009
BBPE	0.477	0.199	−0.856	0.017
LAPE	0.574	−0.399	0.255	0.701
DAPE	0.579	−0.317	0.235	−0.713

Note 1: PC: principal component.

Note 2: BBDE: banking branch density; BBPE: banking branch penetration; LAPE: loan account penetration; and DAPE: deposit account penetration.

Table D2. PCA-related evidence for deriving the ICT infrastructure index.

Part A: Eigen analysis of correlation matrix				
PC	**Eigen value**	**Proportion**	**Cumulative value**	**Cumulative proportion**
1	2.224	0.741	2.224	0.741
2	0.479	0.160	2.703	0.901
3	0.297	0.099	3.000	1.000
Part B: Eigen vectors (component loadings)				
Variable	**PC1**	**PC2**	**PC3**	
TELE	0.604	−0.040	−0.796	
MOBP	0.567	−0.681	0.4639	
INTE	0.561	0.731	0.3887	

Note 1: PC: principal component.

Note 2: TELE: telephone landlines; MOBP: mobile penetration; and INTE: internet users.

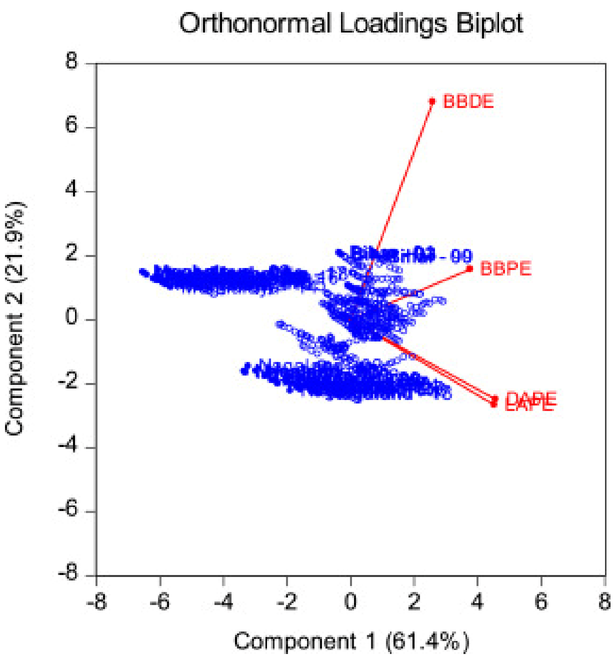

Fig. D1. **Variable loading plots for deriving CIFI** ***Note***: All variables are defined above.

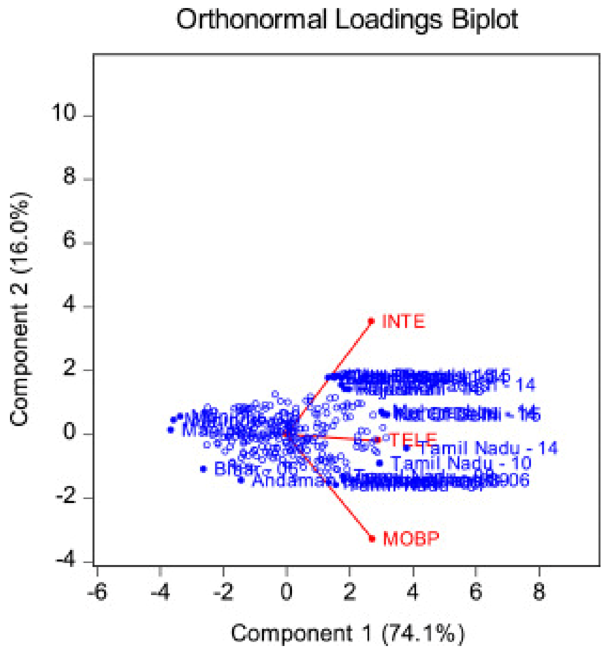

Fig. D2. **Variable loading plots for deriving CIIC** ***Note***: All notations are defined earlier.

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Biographies

Rudra P. Pradhan is a SAP Fellow and an Associate Professor at Indian institute of Technology Kharagpur, India, where he has been associated with Vinod Gupta School of Management and RCG School of Infrastructure Design and Management. Pradhan is affiliated with various professional journals like *Technological Forecasting and Social Change, Telecommunications Policy, Applied Economics, International Economics, Cities, IEEE Transactions on Engineering Management, Empirica, Neural Computing and Applications, Technology in Society, and Review of Economics and Finance*. He is currently associate editors of International Journal of Innovation and Technology Management, Heliyon and Journal of Economic Development. Pradhan has been a visiting scholar to *University of Pretoria*, Republic of South Africa and a visiting professor to *Asian Institute of Technology*, Thailand.

Mak B. Arvin is a Full Professor of Economics at Trent University, Peterborough, Ontario, Canada, where he has been a faculty member for the past 34 years. Arvin's research has resulted in over 180 publications in journals, edited volumes, and books. He has served on the editorial board of over a dozen professional journals and is the former Editor-in-Chief of the *International Journal of Happiness and Development* and the *International Journal of Education Economics and Development.* Arvin has been a visiting professor to Boston College and a consultant to the IFO Institute for Economic Research, Germany. His latest book is the *Handbook on the Economics of Foreign Aid* published in 2015 (with Byron Lew).

Mahendhiran Nair is the Pro-Vice Chancellor (Research Engagement and Impact) and a Professor in the Business School at Sunway University, Malaysia . He is a Fellow of CPA (Australia), Fellow of Academy of Sciences Malaysia and a member of the National Science Council of Malaysia. Mahendhiran leads a research team that studies the impact of ICT and innovation ecosystems on socioeconomic development in emerging countries. He has published his research work in leading international journals and presented in high-impact conferences and forums. He has been a subject matter expert on the knowledge economy and the development of innovation ecosystems for government agencies, public policy organisations and 'think-tanks' in the Asia-Pacific region .

John H. Hall is a Full Professor of Finance and Head of the Department at Department of Financial Management, University of Pretoria, Republic of South Africa. He has been an academic for more than 20 years and has presented numerous papers (some of which has received best paper awards) at national and international conferences. Hall is a South African National Research Foundation rated researcher.

Sara E. Bennett is an Associate Professor of Finance in the College of Business at the University of Lynchburg in Lynchburg, VA, USA where she currently serves as department chair for Business Administration. Her areas of research interest include macroeconomics, financial development, ICT infrastructure, corporate financial management, and financial derivatives. She is the author of several papers and reviews in refereed journals in the area of finance and economics.

Notes

[1]See James (2012) and Wang and Chien (2007) for more details.
[2]See, for example, Pradhan et al. (2018a), (2018b), (2018c), Chakravarty and Pal (2013), and Beck et al. (2007).
[3]Note that PCA has its limitations, like any other estimation mechanism. These include elucidation issues, scaling complications, and higher-order covariance difficulties.