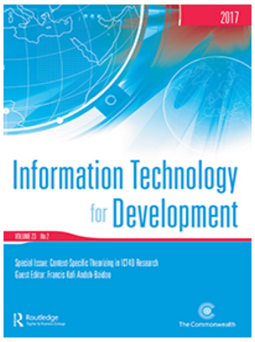

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ABSTRACT
This paper examines causal relationships between telecommunications infrastructure and usage (TEL), foreign direct investment (FDI), and economic growth in the Asian-21 countries for the period 1965–2012. TEL is defined in terms of the prevalence of telephone main lines, mobile phones, internet servers and users, as well as the extent of fixed broadband. These measures are considered both individually and collectively in the form of a composite index of TEL. We report results on long-run relationships between TEL, FDI, and economic growth. We also use a panel vector auto-regression model to reveal the nature of Granger causality among the three variables. Results from these causal relationships provide important policy implications to the Asian-21 countries.

KEYWORDS
Adoption and diffusion of IT and rate of uptake; development issues; sustainable development in developing and transition economies; IT policy; IT strategies for development (national and sectoral)

1. Introduction

Technological change plays a key role in the process of economic development. In contrast to the traditional economic-theoretic framework for analyzing economic growth, where technological change was left as an unexplained residual, recent growth literature has highlighted the dependence of economic growth rates on technological change. Technological advancement can take place through a variety of channels that involve the transformation of ideas and adoption of new technologies from both home and overseas. Chief among these evolutions are improvements in telecommunications infrastructure and usage (hereafter, TEL). Figure 1 illustrates the possible direct and indirect links between TEL and economic growth. A key aim of this paper is to scrutinize the causal linkages between TEL and economic growth for Asian-21 countries in the presence of a third variable, namely foreign direct investment (FDI), which has obvious possible links to both TEL and economic growth.

Endogenous growth theory as articulated by Bevan and Estrin (2004), Brems (1970), Carstensen and Toubal (2004), Chan, Hou, Li, and Mountain (2014), De Mello (1997, 1999),

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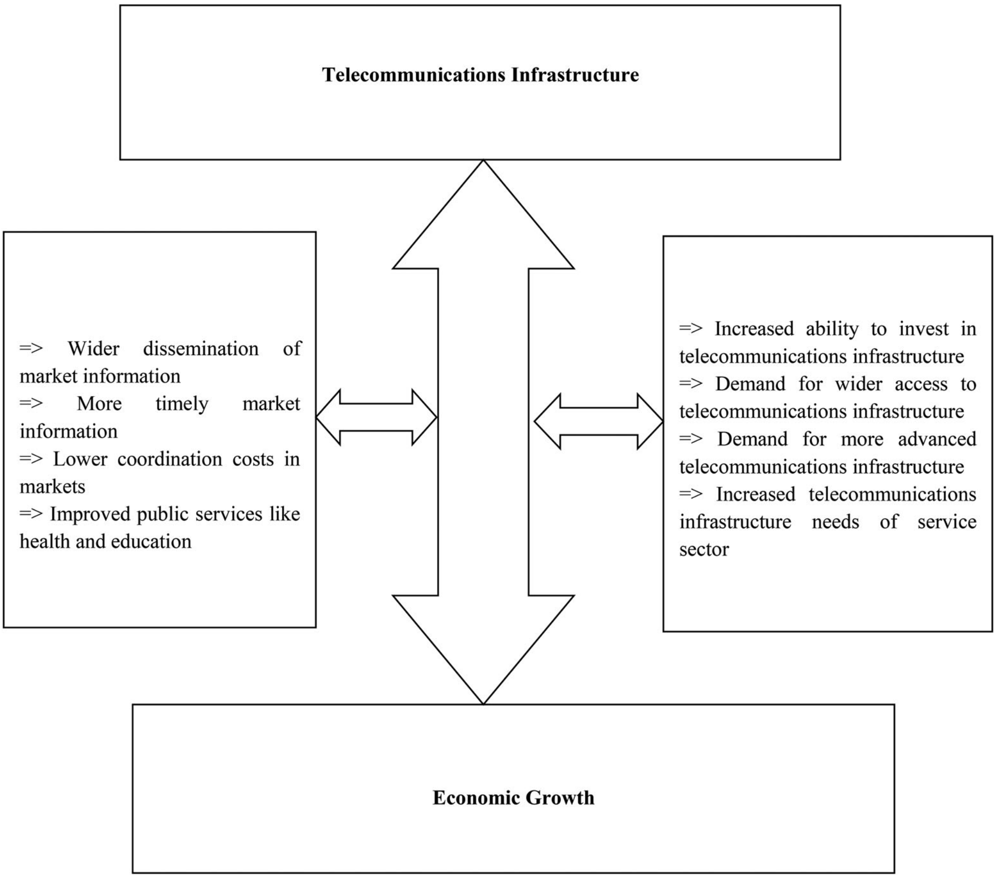

Figure 1. Telecommunications Infrastructure and Economic Growth: possible sub-links. Source: Dutta (2001).

Ilhan (2007), Qi (2007), Romer (1986, 1990), and others highlight that FDI is key in fostering long-run economic growth as it facilitates efficient inter-temporal allocation of resources, capital accumulation, and technological innovation. Balasubramanyam, Salisu, and Sapsford (1999) in particular underscore the beneficial effects of FDI on economic growth. However, as Barro and Sala-i-Martin (1995) assert, the impact of FDI is endogenous since they are a regular part of the process of economic growth. Thus, while FDI may lead to economic growth, the latter may itself lead to further FDI. The theoretical link between FDI and economic growth is summarized in Figure 2.

FDI can also be linked to TEL (see, for instance, Reynolds, Kenny, Liu, & Qiang, 2004; Mody, 1997 for discussion). The possible causal links of TEL to both FDI and economic growth are discussed later in this paper.

This paper contributes to the literature in two ways. First, it uses the endogenous growth theory proposed by Romer (1986, 1990) to show that there are complex relationships between the development of the telecommunication sector, FDI, and economic growth in both the short run and long run. Second, although several papers have considered the causal nexus between FDI and economic growth, or between different

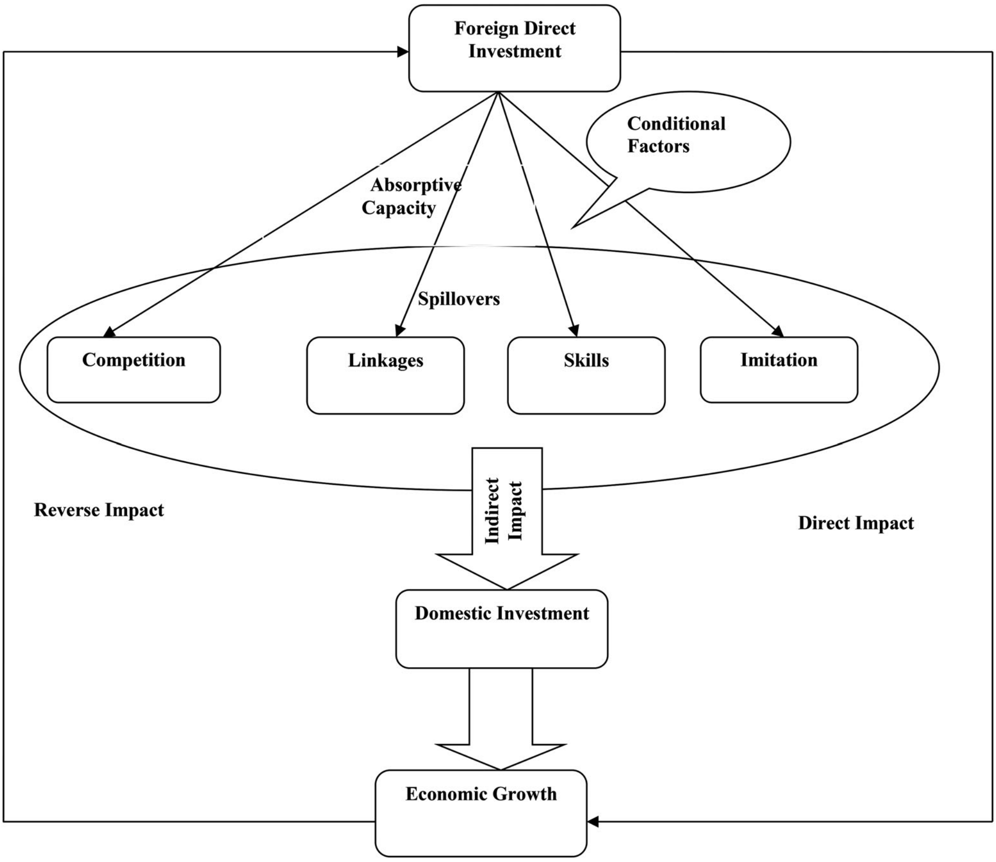

Figure 2. Conceptual framework of the possible causal patterns between FDI and economic growth. Source: Nowbutsing (2009).

Notes: TML: telephone landlines; MOB: mobile phones; INU: internet users; INS: internet servers; FIB: fixed broadband; TII: telecommunications infrastructure index; GDP: per capita economic growth rate; FDI: foreign direct investment; $H_{1A,\ B}$: telecommunications index Granger-causes economic growth and vice versa; $H_{2A,\ B}$: telecommunications index Granger-causes foreign direct investment and vice versa; $H_{3A,\ B}$: telecommunications landlines Granger-causes economic growth and vice versa; $H_{4A,\ B}$: telecommunications landlines Granger-causes foreign direct investment and vice versa; $H_{5A,\ B}$: mobile phones Granger-causes economic growth and vice versa; $H_{6A,\ B}$: mobile phones Granger-causes foreign direct investment and vice versa; $H_{7A,\ B}$: foreign direct investment Granger-causes economic growth and vice versa; $H_{8A,\ B}$: internet users Granger-causes economic growth and vice versa; $H_{9A,\ B}$: internet users Granger-causes foreign direct investment and vice versa; $H_{10A,\ B}$: internet servers Granger-causes economic growth and vice versa; $H_{11A,\ B}$: internet servers Granger-causes foreign direct investment and vice versa; $H_{12A,\ B}$: broadband Granger-causes economic growth and vice versa; $H_{13A,\ B}$: broadband Granger-causes foreign direct investment and vice versa.

measures of TEL and economic growth, we bring together these two empirical literatures by considering the causal link between all three variables.[1] Evidently, the causal link between any of these two variables is considered in the presence of the third variable. During the course of our empirical investigation we also examine and reveal the nature of a possible causal link between TEL and FDI.[2] Furthermore, unlike earlier research, we utilize six different measures of TEL, including a composite index combining the other five measures. Our composite index is constructed using principal component analysis (PCA). Finally, and contrary to earlier work, our paper focuses on the links between the variables by using panel cointegration and causality tests using a sample of Asian-21 countries over the period 1965–2012. Our advanced panel data estimation method allows for more robust estimates by utilizing variations between countries as well as variation over time.

The paper provides robust estimates of the endogenous relationship between development of the telecommunication sector, inflow of FDIs, and economic growth in the Asian economies. Understanding the complex relationships between these three variables provide valuable insights into the type of policies and strategies that these countries should pursue to achieve sustainable economic growth in the long run.

The remainder of this paper is organized as follows. Section 2 provides an overview on two strands of the economic growth literature: one examining the relationship between FDI and economic growth and the other exploring the nexus between TEL and economic growth. Section 3 describes the variables, the samples, and the data. Section 4 presents our empirical methodology and this is followed by a discussion of the results. The final section contains a summary and the policy implications of our results.

2. Brief overview of literature

There is extensive literature showing a direct association between FDI and economic growth (as discussed in Ahmad and Hamdani, 2003; Akinlo, 2004; Chan et al., 2014; De Mello, 1997, 1999; Mankiw, Romer, & Weil, 1992). FDI provides the much needed capital and technology to stimulate economic activity and growth. Similarly, economic growth tends to increase the standard of living and foreign firms capitalize on the increasing purchasing power of consumers as they open up new businesses to enhance their market share. Economic growth also likely results in improvements in infrastructure and other support systems to enhance productivity and reduce the cost of doing business. These measures encourage foreign firms to relocate their businesses in countries that give them a competitive advantage, enabling them to increase market shares, lower costs of production, and minimize economic risks. Competitive advantage considerations are important reasons for firms to expand their global supply chains, leading to enhanced FDI flows.

Four possible relationships have been identified and validated in the empirical literature on the causal linkages between FDI and economic growth, as measured by GDP. These are unidirectional FDI-led economic growth (the supply-leading hypothesis – SLH); unidirectional economic growth-led FDI (the demand-following hypothesis – DFH); bi-directional relationship between FDI and economic growth (the bi-directional feedback-hypothesis – BFH); and neutrality hypotheses (also known as the no causality hypothesis – NCH).

First, SLH suggests a unidirectional Granger causality running from FDI to economic growth – a likely scenario for a FDI-dependent economy where FDI is a prerequisite for economic growth. In this case, FDI stimulates growth for the host countries by increasing the capital stock, creating new job opportunities, and easing the transfer of technology (Borensztein, De Gregorio, & Lee, 1998; De Gregorio, 2003; De Mello, 1997). Therefore, theoretically, in such a case, inadequate provision of FDI may limit economic growth or may result in poor economic performance. Many studies (Abdelhafidh, 2013; Cheong Tang & Wong, 2011; Cuadros, Orts, & Alguacil, 2004; Dua & Rashid, 1998; Fedderke & Romm, 2006; Hsiao & Hsiao, 2006; Lean & Tan, 2011; Lee, 2010; Lee & Tan, 2006; Qi, 2007; Ramírez, 2000; Yao, 2006; Zhang, 2001) support this hypothesis.

Second, DFH suggests a unidirectional causality from economic growth to FDI. The idea here is that rapid economic growth can create new investment opportunities in the host country and hence, attracts FDI inflows to the host country. The studies which support this hypothesis are Lean and Tan (2011), Mah (2010), Lee (2009), Galan and Oladipo (2009), Ang (2009), Lee and Tan (2006), Choe (2003), Alguacil, Cuadros, and Orts (2002), Zhang (2001), Liu, Wang, and Wei (2001), and Rodrik (1999).

Third, BFH purports that FDI and growth complement each other. Chan et al. (2014), Goswami and Saikia (2012), Herzer (2008), Dash and Sharma (2011), Ahmed, Cheng, and Messinis (2011), Lee (2010), Al Nasser (2010), Liu, Shu, and Sinclair (2009), Chakraborty and Nunnenkamp (2008), Herzer (2008), Duasa (2007), Hsiao and Hsiao (2006), Lee and Tan (2006), Chowdhury and Mavrotas (2005), Hsiao and Shen (2003), Liu et al. (2001), Shan (2002), Xiaohui, Burridge, and Sinclair (2011), and Ericsson and Irandoust (2001) present evidence in support of this hypothesis.

Finally, NCH suggests that there is no causal connection between FDI and economic growth. It implies that policies to promote FDI will not have any effects on economic growth. This is supported by few papers including Yalta (2013), Herzer, Klasen, and Nowak-Lehmann (2008), Duasa (2007), and Ericsson and Irandoust (2001).

Table 1 presents a summary of these studies.

Analogously, the empirical literature on the causal link between TEL and economic growth offers a disparate spectrum of results in relation to our four hypotheses. First, using a dynamic panel data method, Datta and Agarwal (2004) show that there is a long-run relationship between telecommunication infrastructure and economic growth for 22 OECD countries. The study clearly illustrates that there is a strong correlation between telecommunication infrastructure and economic growth. A more recent study by Levendis and Lee (2013) using the generalized method of moments estimator of Arellano–Bond method shows that telephone penetration has a positive impact on economic growth in Asian countries. Several other studies have also shown unidirectional causality running from TEL to economic growth maintaining that the former is a prerequisite for economic growth. In this context, Mehmood and Siddiqui (2013), Ahmed and Krishnasamy (2012), Shiu and Lam (2008a), Yoo and Kwak (2004), Cieslik and Kaniewsk (2004), Chakraborty and Nandi (2003), Dutta (2001), and Roller and Waverman (2001) find results in support of a TEL-led economic growth hypothesis.

Second, a unidirectional causality running from economic growth to TEL suggests that rapid economic growth can generate higher demand for TEL. Pradhan, Arvin, Norman, and Bele (2014), Pradhan, Bele, and Pandey (2013a), Lee (2011), Veeramacheneni, Ekanayake, and Vogel (2007), and Beil, Ford, and Jackson (2005) support the validity of economic growth-led TEL hypothesis.

Third, the feedback hypothesis (FBH) suggests that TEL and economic growth are interrelated and reinforce each other. Pradhan, Bele, and Pandey (2013b), Chakraborty and Nandi (2011, 2009), Lam and Shiu (2010), Ramlan and Ahmed (2009), Zahra, Azim, and Mahmood (2008), Shiu and Lam (2008b), Yoo and Kwak (2004), Chakraborty and Nandi (2009, 2011), Cronin, Parker, Colleran, Herbert, and Lewitzky (1993), and Cronin, Colleran, Herbert, and Lewitzky (1993) find evidence in favor of this hypothesis.

Finally, if there is no causality between TEL and economic growth (also known as neutrality hypothesis), this implies that policies that promote TEL will not affect economic growth. Some studies (Dutta, 2001; Pradhan, Arvin, Mittal, & Bahmani, 2016; Shiu & Lam, 2008b; Veeramacheneni et al., 2007) support this hypothesis.

Table 1. Summary of findings on the direction of causality between FDI and economic growth.

Study	Region	Method	Period
Case 1: Studies supporting SLH			
Abdelhafidh (2013)	North African countries	MVGC	1970–2007
Lean and Tan (2011)	Malaysia	MVGC	1970–2009
Cheong Tang and Wong (2011)	Cambodia	TVGC	1994–2006
Lee (2010)	Japan and World	BVGC	1977–2006
Qi (2007)	47 Countries	MVGC	1970–2002
Hsiao and Hsiao (2006)	East and South East Asian countries	MVGC	1986–2004
Yao (2006)	China	TVGC	1978–2000
Lee and Tan (2006)	ASEAN countries	MVGC	1990–2000
Fedderke and Romm (2006)	South Africa	BVGC	1960–2003
Cuadros et al. (2004)	3 Latin American countries	BVGC	1980–2000
Zhang (2001)	East Asia and Latin America countries	BVGC	1980–2007
Pradhan et al. (2000)	Mexico	BVGC	1960–1995
Dua and Rashid (1998)	India	BVGC	1992–1994
Case 2: Studies supporting DFH			
Lean and Tan (2011)	Malaysia	TVGC	1970–2009
Mah (2010)	China	BVGC	1983–2001
Alguacil et al. (2002)	Mexico	MVGC	1980–1999
Lee (2009)	Malaysia	BVGC	1970–2000
Galan and Oladipo (2009)	Mexico	TVGC	1980–2002
Ang (2008)	Malaysia	MVGC	1965–2004
Lee and Tan (2006)	ASEAN countries	MVGC	1990–2000
Choe (2003)	80 countries	MVGC	1971–1995
Zhang (2001)	East Asia and Latin America countries	BVGC	1980–2007
Liu et al. (2001)	China	MVGC	1984–1998
Case 3: Studies supporting FBH			
Goswami and Saikia (2012)	India	TVGC	1991–2010
Herzer (2008)	Germany	TVGC	1980–2008
Dash and Sharma (2011)	India	MVGC	1991–2006
Ahmed et al. (2011)	Sub-Sahara African countries	MVGC	1991–2001
Lee (2010)	Japan and World	BVGC	1977–2006
Al Nasser (2010)	14 Latin American countries	MVGC	1978–2003
Liu et al. (2009)	10 Asian economies	MVGC	1970–2002
Chakraborty and Nunnenkamp (2008)	India	MVGC	1987–2000
Herzer (2008)	14 Industrialized countries	BVGC	1971–2005
Duasa (2007)	Malaysia	BVGC	1990–2002
Hsiao and Hsiao (2006)	East and South East Asian countries	MVGC	1986–2004
Lee and Tan (2006)	ASEAN countries	MVGC	1990–2000
Chowdhury and Mavrotas (2005)	Chile, Malaysia, and Thailand	BVGC	1969–2000
Hsiao and Shen (2003)	China	BVGC	1982–1998
Liu et al. (2002)	China	TVGC	1981–1997
Shan (2002)	China	MVGC	1986–1998
Xiaohui et al. (2011)	China	BVGC	1981–1997
Ericsson and Irandoust (2001)	OECD	TVGC	1970–1997
Studies supporting NOH			
Herzer (2008)	28 Developing countries	MVGC	1970–1995
Duasa (2007)	Malaysia	BVGC	1990–2002
Ericsson and Irandoust (2001)	OECD	TVGC	1970–1997

Notes: Supply-leading hypothesis (SLH): unidirectional causality from foreign direct investment (FDI) to economic growth (GDP); demand-following hypothesis (DFH): unidirectional causality form GDP to FDI; feedback hypothesis (FBH): bidirectional causality between FDI and GDP; no-causality hypothesis (NOH), no causality between FDI and GDP. BVGC: bivariate Granger causality; TVGC: trivariate Granger causality; QVGC: quadvariate Granger causality; MVGC: multivariate Granger causality.

Table 2 presents a synopsis of the findings of these studies.

3. Data, variables, and samples

Annual data for the Asian-21 countries spanning over 1965–2012 were obtained from the *World Development Indicators* published by the World Bank. Appendix A lists these

Table 2. Summary of studies on telecommunications infrastructure/usage and economic growth.

Study	Region	Method	Period
Case 1: Studies supporting SLH			
Mehmood and Siddiqui (2013)	23 ACs	DPDM	1990–2010
Shiu and Lam (2008a)	China	DPDM	1978–2004
Yoo and Kwak (2004)	Korea	GCT	1965–1998
Cieslik and Kaniewsk (2004)	Poland	GCT	1989–1998
Chakraborty and Nandi (2003)	12 ACs	GCT	1975–2000
Dutta (2001)	15DCs and 15 ICs	GCT	1960–1993
Case 2: Studies supporting DFH			
Pradhan et al. (2013b)	34 OECD countries	DPDM	1961–2011
Lee et al. (2012)	3 NACs	GCT	1975–2009
Shiu and Lam (2008a)	China	DPDM	1978–2004
Beil et al. (2005)	USA	GCT & MST	1947–1996
Beil et al. (2005)	USA	GCT & MST	1947–1996
Case 3: Studies supporting FBH			
Pradhan et al. (2013b)	34 OECD countries	DPDM	1990–2010
Chakraborty and Nandi (2011)	93 Countries	GCT	1985–2007
Lam and Shiu (2010)	105 Countries	DPDM	1980–2006
Chakraborty and Nandi (2009)	DCs	GCT	1980–2001
Zahra et al. (2008)	23 Countries	GCT	1990–2007
Shiu and Lam (2008b)	105 Countries	DPDM	1980–20
Wolde-Rufael (2007)	USA	GCT	1947–1996
Cronin et al. (1991)	USA	GCT	1958–1988
Case 4: Studies supporting NLH			
Ramlan and Ahmed (2009)	Malaysia	GCT	1965–2005
Shiu and Lam (2008a)	China	DPDM	1978–2004
Veeramacheneni et al. (2007)	10 LACs	GCT	1975–2003

Notes: Supply-leading hypothesis (SLH): unidirectional causality from telecommunications infrastructure/usage (TEL) to economic growth (GDP); demand-following hypothesis (DFH): unidirectional causality form GDP to TEL; feedback hypothesis (FBH): bidirectional causality between TEL and GDP; no-causality hypothesis (NOH), no causality between TEL and GDP. GCT: Granger causality test; MST: modified Sims test; DCs: developing countries; ICs: industrialized countries; ACs: Asian countries; NACs: Northeast Asian countries; LACs: Latin American countries; DPDM: dynamic panel data model.

countries. The variables used in this analysis are real per capita economic growth (variable: GDP), inflows of real foreign direct investment as a percentage of gross domestic product (variable: FDI), and telecommunications infrastructure and usage (variable: TEL). TEL is represented by six possible variables: number of telephone landlines per thousand population (variable: TML); number of mobile phones per thousand population (variable: MOB); number of internet users per thousand population (variable: INU); number of internet servers per thousand population (variable: INS); number of fixed broadband per thousand population (variable: FBB); and a composite index combining the other five measures of TEL, using principal component analysis (variable: TII).[3] Given that the data for some of our variables is not available over the entire 1965–2012 period, we present results for three estimation periods (1965–2012, 1990–2012, and 2001–2012) depending on which measure of TEL we use (see below). All the variables are converted into their natural logarithms for our estimation.

Table 3 presents a summary of these variables, while Tables 4 and 5 supply the descriptive statistics and the correlations, respectively. The results of the correlation matrix indicate that the first five indicators of TEL (i.e. TML, MOB, INU, INS, and FBB) are highly correlated. Thus, the problem of multicollinearity would arise if these variables were used simultaneously. This affirms our conviction that only one of these variables should be used at a time in our investigation process.

Table 3. List of variables.

Variable	Definition
TML	Telephone landlines per thousand population
MOB	Mobile phone subscribers per thousand population
INU	Internet users per thousand population
INS	Internet servers per thousand population
FBB	Fixed broadband per thousand population
TII	Composite index of telecommunications infrastructure: Combining TML, MOB, INU, INS, and FBB using principal component analysis
FDI	Foreign direct investment as a % of gross domestic product
GDP	Economic growth, defined as % change in per capita gross domestic product

Notes: All monetary measures are in real US dollars;
Variables above are defined in the *World Development Indicators* and published by the World Bank.

A panel data analysis is the most appropriate methodology to use given long span of the data used in this study. The following general model was employed to describe the long-run relationship between GDP, FDI, and TEL.

$$\mathrm{GDP}_{it} = \alpha_{it} + \beta_{1i}\mathrm{TEL}_{it} + \beta_{2i}\mathrm{FDI}_{it} + \varepsilon_{it}, \tag{1}$$

where $i = 1, 2, \ldots, N$ represents each country in the panel; and $t = 1, 2, \ldots, T$ refers to the time period in the panel. In other variations of Equation (1) other variables (*TEL* or *FDI*) serve as the dependent variable to allow for the possibility that causation may flow in either direction.

The parameters β_1, and β_2 represent the long-run elasticity estimates of GDP with respect to TEL and FDI. TEL represents six possible variables: TML, MOB, INU, INS, FBB, and TII which we used one at a time, representing Models 1–6 as presented below. The primary objective of this study was to estimate the parameters in Equation (1) and

Table 4. Summary Statistics for the Variables.

Variables	Mean	Med	Max	Min	Std	Skew	Kur
1965–2012							
GDP	1.43	1.45	1.68	−0.33	0.12	−6.69	80.5
FDI	1.05	1.03	1.15	1.00	0.03	1.25	4.04
TML	0.74	0.93	1.79	−1.07	0.76	−0.48	2.04
1990–2012							
GDP	1.44	1.45	1.59	1.03	0.08	−2.17	10.6
FDI	1.05	1.04	1.16	1.01	0.03	1.16	4.50
TML	1.11	1.22	1.79	−0.52	0.55	−0.77	2.78
MOB	1.15	1.54	2.36	−2.10	0.99	−1.03	3.16
INU	0.55	0.88	1.94	−4.28	1.26	−1.26	4.28
TII	0.77	0.76	0.93	0.70	0.06	0.58	2.20
2001–2012							
GDP	1.44	1.46	1.59	1.07	0.08	−2.06	9.51
FDI	1.05	1.04	1.16	1.01	0.03	1.18	4.46
TML	1.19	1.72	1.23	1.79	−0.20	0.46	−0.83
MOB	1.78	1.90	2.36	−0.21	0.41	−1.71	6.58
INU	1.29	1.46	1.94	−0.18	0.52	−0.63	2.38
INS	1.00	0.88	3.44	−1.84	1.16	−0.01	2.11
FBB	0.20	0.29	1.57	−3.0	1.04	−0.73	2.92
TII	0.78	0.76	0.96	0.70	0.06	0.74	2.88

Notes: GDP: per capita economic growth; FDI: foreign direct investment; TML: telephone landlines; MOB: mobile phones; INU: internet users; INS: internet servers; FBB: fixed broadband; TII: telecommunications infrastructure index;
Med: median; Max: maximum; Min: minimum; Std: standard deviation; Skew: skewness; Kur: kurtosis. Values reported here are the natural logs of the variables defined in Table 3. Natural log forms are used in our estimations.

Table 5. The correlation matrix.

Variables	GDP	FDI	TML	MOB	INU	INS	FBB	TII
1965–2012								
GDP	1.00							
FDI	0.08	1.00						
TML	−0.07	0.59*	1.00					
1990–2012								
GDP	1.00							
FDI	0.02	1.00						
TMl	−0.13	0.57*	1.00					
MOB	−0.12	0.37*	0.55*	1.00				
INU	−0.17	0.38*	0.57*	0.93*	1.00			
TII	−0.18	0.60	0.72	0.76*	0.77*			1.00
2001–2012								
GDP	1.00							
FDI	0.03	1.00						
TML	−0.17**	0.58*	1.00					
MOB	−0.24**	0.37*	0.49*	1.00				
INU	−0.28**	0.58*	0.74*	0.82*	1.00			
INS	−0.34*	0.58*	0.69*	0.73*	0.85*	1.00		
FBB	−0.14**	0.61*	0.69*	0.84*	0.89*	0.82*	1.00	
TII	−0.23**	0.70*	0.78*	0.68*	0.86*	0.90*	0.86*	1.00

Notes GDP: per capita economic growth; FDI: foreign direct investment; TML: telephone landlines; MOB: mobile phones; INU: internet users; INS: internet servers; FBB: fixed broadband; TII: telecommunications infrastructure index.
*Statistical level of significance at the 1% level.

conduct panel tests on the causal nexus between the three variables. It was postulated that $\beta_1 > 0$ as higher TEL would likely cause increased GDP. Similarly, we also expected $\beta_2 > 0$, which represents the notion that increased FDI would likely cause increased GDP.

Over the past five decades, several waves of new telecommunication technology have been introduced in the Asian-21 countries. By the middle of the 1960s, use of landline telephones was common in all of these countries. From the 1990s, breakthroughs in mobile communication technology such as mobile phones and internet became popular in the Asian-21 countries. By early 2000s, internet servers and fixed broadband became increasingly prevalent in these counties and they revolutionized the medium of communications. As commented above, to capture the changing telecommunication technology landscape in the Asian-21 countries, our empirical estimations were undertaken over three sample periods depending on the variable that was used to capture TEL: 1965–2012 for TML; 1990–2102 for TML, MOB, INU, and TII; and 2001–2012 with TML, MOB, INU, INS, FBB, and TII.

4. Econometric analysis and empirical results

In this paper, the key theoretical framework that underpins the empirical analysis is the endogenous growth theory. Studies by Romer (1986, 1990) and Lucas (1988) show that technology is an important catalyst for economic development. In this context, efficient, extensive, and denser telecommunications infrastructure contributes to economic development in two ways. First, the telecommunications sector, which is important for the delivery of information and communication technologies' products and services in a digital economy, becomes an important source of revenue for innovation and a knowledge-based economy. Second, telecommunications sector is an important enabler for transmitting information and knowledge to all economic agents in the economy. Hence, in turn, it becomes a key catalyst for improving productivity and economic growth in the economy.

The proponents of the endogenous growth theory also argue that the telecommunications sector has several positive spill-over effects on the economy. It has the ability to increase the wealth potential of economic agents; attract high-quality FDIs supporting a knowledge-based economy; increase inflow of talent from around the world (i.e. encourage brain-gain); and spur research and development activities that spawn new sources of growth. These benefits will deepen the impact of telecommunications sector on FDI and economic growth. Hence, the endogenous growth theory postulates that these positive externalities are key drivers for sustained economic development in the long run.

In the context, using a sample of Asian-21 countries, we tested the following three general hypotheses:

TEL Granger-causes economic growth and vice versa.

FDI Granger-causes economic growth and vice versa.

TEL Granger-causes FDI and vice versa.

More specifically, we tested the followings hypotheses:

$H_{1A,\ B}$: TII Granger-causes economic growth and vice versa

$H_{2A,\ B}$: TII Granger-causes FDI and vice versa

$H_{3A,\ B}$: TML Granger-causes economic growth and vice versa

$H_{4A,\ B}$: TML Granger-causes FDI and vice versa

$H_{5A,\ B}$: MOB Granger-causes economic growth and vice versa

$H_{6A,\ B}$: MOB Granger-causes FDI and vice versa

$H_{7A,\ B}$: FDI Granger-causes economic growth and vice versa

$H_{8A,\ B}$: INU Granger-causes economic growth and vice versa

$H_{9A,\ B}$: INU Granger-causes FDI and vice versa

$H_{10A,\ B}$: INS Granger-causes economic growth and vice versa

$H_{11A,\ B}$: INS Granger-causes FDI and vice versa

$H_{12A,\ B}$: FBB Granger-causes economic growth and vice versa

$H_{13A,\ B}$: FBB Granger-causes FDI and vice versa

Figure 3 summarizes these hypotheses, which describe the direction of possible causality among the variables.

Our estimation procedure involved utilizing the following tests: the panel unit root test, the panel cointegration test, and the panel Granger causality test.

4.1. The panel unit root test and results

The panel unit root test was used to estimate the degree (or order) of integration between GDP, FDI, and TEL. Several unit root tests were utilized in this paper. Specifically, we conducted a homogeneous unit root test proposed by Levin, Lin, and Chu (2002), hereafter

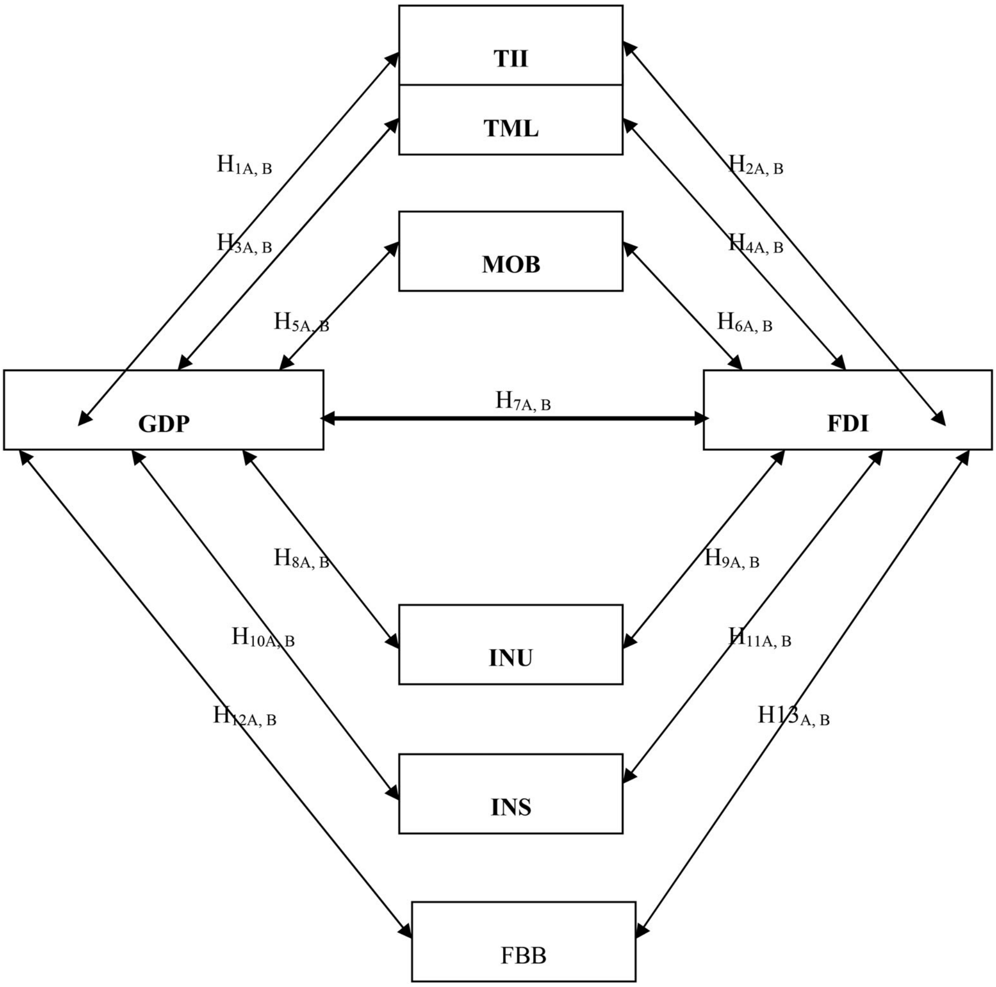

Figure 3. Possible causality among telecommunications infrastructure/usage, foreign direct investment, and economic growth.

LLC; three heterogeneous unit root tests proposed by Im, Pesaran, and Shin (2003), hereafter **IPS**, Maddala and Wu (1999), hereafter **MW**, and Choi (2001), hereafter **CH**; and a stationarity panel test proposed by Hadri (2000), hereafter **HAD**.

For each of the estimation, we tested the unit root by using two different models: (1) a model that has a constant and a deterministic trend; and (2) a model that has only a constant and no trend.

The LLC test is the most widely used panel unit root test and was based on Augmented Dickey–Fuller (ADF) principle, but in panel settings. The following regression model was used for LLC estimation:

$$\Delta Y_{it} = \alpha_i + \gamma Y_{i,t-i} + \sum_{j=1}^{p_i} \beta_j \Delta Y_{i,t-j} + \varepsilon_{it}, \tag{2}$$

where Δ was the first difference operator; Y_{it} was the series of observation for country

i ($i = 1, 2, .., N$) and time period t ($t = 1, 2, \ldots, T$); p_i was the number of lags in the regression; and ε_{it} was the error term, assumed to be IID (0, σ^2) and independent across units of the sample.

The null hypothesis of non-stationary was H_0: $\gamma_i = \gamma = 0$ for all i against the alternative H_A: $\gamma_i = \gamma < 0$, presuming all series are stationary. The LLC test assumed homogeneity in the dynamics of autoregressive coefficients for all panel units; that is, γ_i is identical across countries.

The IPS test is an extension of the LLC test that relaxed the homogenous assumptions by allowing for heterogeneity in the autoregressive coefficients for all panel members (γ varies across units under the alternative hypothesis). The alternative hypothesis implied that some or all individual series were stationary.

Breitung (2000) showed that when individual-specific trends were included, the IPS test suffered from loss of power due to bias correction. The study proposed an alternative unit root test which corrected for the loss of power and which also offered greater power than the IPS test. The null hypothesis of Breitung's test was that the panel series exhibited non-stationary difference and the alternative hypothesis assumed the panel series was stationary.

In contrast to the IPS test which was a parametric and asymptotic test, Maddala and Wu (1999) and Choi (2001) proposed a non-parametric and exact test. The latter was based on the Fisher (1932) test and combines the p-values from the individual unit root tests. The test was superior to IPS test (see, Maddala & Kim, 1998; Maddala & Wu, 1998). The advantage was that its value did not depend on different lag lengths in the individual ADF regressions. The test statistic was expressed as follows:

$$\lambda = -\sum_{i=1}^{n} \log_e(p_i) \sim \chi^2_{2n(d.f.)}, \tag{3}$$

where p_i was the p-value from the ADF unit root tests for unit i. The null hypothesis was that each series in the panel had a unit root, that is, H_0: $p_i = 0$ for all i and the alternative hypothesis was that not all individual series had a unit root, that is, H_A: $p_i < 0$ for all $i = 1, 2, \ldots, N_1$ and $p_i = 0$ for all $i = N_1 + 1, \ldots, N$.

Additionally, the Choi (2006) test followed the estimation of the below regression equation.

$$Z = \frac{1}{\sqrt{n}} \sum \Phi^{-1}(p_i) \sim N(0, 1), \tag{4}$$

where Φ^{-1} is the inverse of the standard normal cumulative distribution function. The null hypothesis for these tests can be written as

$$H_0{:}\alpha_i = 0 \quad \text{for all } i.$$

On the contrary, the alternative hypothesis can be written as

$$H_A{:}\begin{cases} \alpha_i = 0 \text{ for } i = 1, 2, \ldots N_i \\ \alpha_i < 0 \text{ for } i = N + 1, N + 2, \ldots, N \end{cases}. \tag{5}$$

Table 6 shows the results of the panel unit root tests for each variable. It was observed that the level values of all series (GDP, FDI, TII, TML, MOB, INU, INS, and FBB) were

Table 6. Results of panel unit roots test (LLC statistic).

Variable	Period	Level	M1	M2	M3	M4	M5	M6	Unit root inference
GDP	1	25.5*	25.5*	25.5*	25.5*	25.5*	25.5*	25.5*	**I (1)**
	2	12.5*	12.5*	12.5*	12.5*	12.5*	12.5*	12.5*	**I (1)**
	3	14.3*	14.3*	14.3*	14.3*	14.3*	14.3*	14.3*	**I (1)**
FDI	1	3.88*	3.88*	3.88*	3.88*	3.88*	3.88*	3.88*	**I (1)**
	2	5.09*	5.09*	5.09*	5.09*	5.09*	5.09*	5.09*	**I (1)**
	3	12.1*	12.1*	12.1*	12.1*	12.1*	12.1*	12.1*	**I (1)**
TML	1		6.37*						**I (1)**
	2		9.33*						**I (1)**
	3		20.1*						**I (1)**
MOB	2			5.19*					**I (1)**
	3			16.6*					**I (1)**
INU	2				9.17*				**I (1)**
	3				12.2*				**I (1)**
INS	3					24.8*			**I (1)**
FBB	3						13.8*		**I (1)**
TII	2							6.64*	**I (1)**
	3							13.6*	**I (1)**
Cointegration inference	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	

Notes: GDP: per capita economic growth; FDI: foreign direct investment; TML: telephone landlines; MOB: mobile phones; INU: internet users; INS: internet servers; FBB: fixed broadband; TII: telecommunications infrastructure index. M1: indicates Model 1 (causal nexus between GDP, FDI, and TML); M2: indicates Model 2 (causal nexus between GDP, FDI, and MOB); M3: indicates Model 3 (causal nexus between GDP, FDI, and INU); M4: indicates Model 4 (causal nexus between GDP, FDI, and INS); M5: indicates Model 5 (causal nexus between GDP, FDI, and FBB); M6: indicates Model 6 (causal nexus between GDP, FDI, and TII). 1: Period 1 (1965–2012); 2: Period 2 (1990–2012); and 3: Period 3 (2001–2012). The study conducted one homogeneous unit root test (Levin et al., 2002, hereafter **LLC**), three heterogeneous unit root tests (Im et al., 2003, hereafter **IPS**; Maddala & Wu, 1999, hereafter **MW**; Choi, 2001, hereafter **CH**) and the stationarity panel test by Hadri (2000), hereafter **HAD**. However, only Hadri *Z*-stat (at first difference) is reported here at both intercept and trend. The study conducted Johansen's (1988, 1995) cointegration test and the results are reported in the form of "Y", indicating the presence of cointegration between the variable in the different models.
*Statistical significance at 1%; I (1) indicates integration of order one.

non-stationary and all variables were stationary at the 1% significance level in the first difference, that is, all variables were integrated of order one [i.e. I (1)].

4.2. The panel cointegration test and results

We have established that the model's variables were non-stationary I (1) variables. Hence, we considered vector autoregressive (VAR) order p to capture the dynamics between the TEL, FDI, and economic growth, as shown below:

$$Y_{it} = \beta_i Y_{it-1} + \beta_2 Y_{it-2} + \ldots + \beta_p Y_{it-p} + BX_{it} + \varepsilon_{it}, \tag{6}$$

where Y_{it} was a three vector non-stationary I (1) variables and X_{it} was a d-vector of exogenous variables and ε_{it} is a random error.

The VAR can be written as

$$\Delta Y_{it} = \Pi Y_{it-1} + \sum_{s=1}^{q-1} \Gamma_s \Delta Y_{it-s} + BX_{it} + \varepsilon_{it}, \tag{7}$$

with

$$\Pi = \sum_{s=1}^{q} A_s - I, \tag{8}$$

$$\Gamma_s = -\sum_{j=s+1}^{q} A_j. \tag{9}$$

The number of cointegration relationships in the model represented by Equation (6) could be determined by the coefficient matrix Π, If Π has reduced rank, that is $r < k$, then there exist $k \times r$ matrices α and β each with rank r, such that $\Pi = \alpha\beta'$ and that $\beta' Y_{it}$ is I (0). This implied that r was the number of cointegration relations and each column of β was the cointegration vector. Johansen (1988, 1995) method proposed estimation of the Π matrix from an unrestricted VAR and then tested if the reduced rank of the Π matrix could be rejected. In this context, the Johansen traced statistic (T) tests the null hypothesis of r cointegrating relations against the alternative of k cointegrating relations, where k was the number of endogenous variables, for $r = 0, 1, \ldots, k–1$. The test was sequential where the null hypothesis of $r = 0$ was not rejected; this implied that there was no cointegration among the time series. On the other hand, if the null hypothesis of $r = 0$ was rejected, and then there existed at least one cointegrating relationship. Next, we tested the null hypothesis that there was at most one cointegrating relationship against the alternative that there were at least two cointegrating relationships. The sequential test continued until the null hypothesis could not be rejected. If none of the series had a unit root, a stationary VAR could be specified to capture the relationship between TEL, FDI, and GDP. Table 6 shows the results of the cointegration test. The results in each case show at least one cointegrating relationship, indicating the presence of a long-run relationship among the variables.

4.3. The panel Granger causality test and results

On the basis of unit root and cointegration test results in the sub-sections above, the following vector error-correction model (VECM) was used to ascertain the nature of the short-run and long-run causal relationships between the three variables.

$$\begin{bmatrix} \Delta \ln GDP_{it} \\ \Delta \ln FDI_{it} \\ \Delta \ln TEL_{it} \end{bmatrix} = \begin{bmatrix} \lambda_{1j} \\ \lambda_{2j} \\ \lambda_{3j} \end{bmatrix} + \sum_{k=1}^{p} \begin{bmatrix} d_{12ik}(L) d_{13ik}(L) d_{13ik}(L) \\ d_{22ik}(L) d_{22ik}(L) d_{23ik}(L) \\ d_{32ik}(L) d_{32ik}(L) d_{33ik}(L) \end{bmatrix} \begin{bmatrix} \Delta \ln GDP_{it-k} \\ \Delta \ln FDI_{it-k} \\ \Delta \ln TEL_{it-k} \end{bmatrix} + \begin{bmatrix} \delta_{1i} ECT_{it-1} \\ \delta_{2i} ECT_{it-1} \\ \delta_{3i} ECT_{it-1} \end{bmatrix} + \begin{bmatrix} \xi_{1it} \\ \xi_{2it} \\ \xi_{3it} \end{bmatrix}, \tag{10}$$

where Δ was first difference filter $(I - L)$; $i = 1, \ldots, N$; $t = 1, \ldots, T$; and ξ_j $(j = 1, \ldots, 6)$ were independently and normally distributed random variables for all i and t with zero mean and finite heterogeneous variances (σ_i^2).

The error-correction terms (ECTs) were derived from the cointegrating equations, and ECTs represented long-run dynamics, akin to an equilibrium process, while the differenced variables represented short-run adjustment dynamics between the variables. We looked for both short-run and the long-run causal relationships. The short-run causal relationship was measured through F-statistics and the significance of the lagged changes in independent variables, whereas the long-run causal relationship was measured through the significance of the t-test of the lagged ECTs. The following restrictions apply to the causal flows between the variables.

For TEL => GDP; and GDP => TEL: $d_{12ik} \neq 0$; $\delta_{1i} \neq 0$; $d_{22ik} \neq 0$; and $\delta_{2i} \neq 0$
For FDI => GDP; and GDP => FDI: $d_{13ik} \neq 0$; $\delta_{1i} \neq 0$; $d_{22ik} \neq 0$; and $\delta_{2i} \neq 0$.
For FDI => TEL; and TEL => FDI: $d_{14ik} \neq 0$; $\delta_{1i} \neq 0$; $d_{44ik} \neq 0$; and $\delta_{4i} \neq 0$

Tables 7 and 8 present a summary of the direction of Granger causality between GDP, FDI, and TEL for different variables characterizing TEL and for different time periods. The tests were conducted for 1%, 5%, and 10% significance levels. Results for the long-run and short-run Granger causality tests are reported below.

4.3.1. Long-run Granger causality results

From Tables 7 and 8 it can be noted that when ΔGDP served as dependent variable, the lagged ECT was statistically significant. In such situation, economic growth tended to converge to its long-run equilibrium path as a response to changes in its repressors – FDI and TEL. Another observable common pattern in these tables was that when ΔINU and ΔMOB were used as dependent variable, the number of internet and mobile phone users per thousand of population tended to converge to their long-run equilibrium paths in response to changes to their regressors (economic growth and FDI). Other than these common results no general pattern emerged in the long run for various time periods that we considered.

4.3.2. Short-run Granger causality results

In contrast to the long-run Granger causality results, the study reveals a wide spectrum of short-run causality results between the three variables. These results are summarized in Table 9 and presented below.

For 1965–2012 period. The study found the existence of unidirectional causality from telecommunications infrastructure (TML) to both economic growth and FDI [GDP ↑ TML; FDI ↑ TML].

For 1990–2012 period. In Model 1, the empirical results showed existence of bidirectional causality between economic growth and FDI [FDI ↕ GDP]. In Model 2, results revealed unidirectional causality from FDI to economic growth [FDI ↓ GDP]. In Model 3, results revealed a unidirectional causality from FDI to economic growth [FDI ↓ GDP] is obtained. Finally, in Model 4 results demonstrated existence of bidirectional causality between FDI and economic growth [FDI ↕ GDP]; and a unidirectional causality from economic growth to telecommunications infrastructure (TII) [GDP ↓ TII]. The finding of bidirectional causality between FDI and economic growth (in favor of FBH) is generally supported by Ahmed et al. (2011), Chakraborty and Nunnenkamp (2008), Hsiao and Hsiao (2006), Hsiao and Shen (2003), Lee and Tan (2006), Liu, Burridge, and Sinclair (2002); Liu et al. (2009), and Shan (2002). On the contrary, the findings of unidirectional causality from FDI to economic growth (in favor of SLH) is congruent with the findings of Dua and Rashid (1998), Lean and Tan (2011), Lee (2010), Lee and Tan (2006), Qi (2007), Ramírez (2000), Cheong Tang and Wong (2011), Yao (2006), and Zhang (2001).

Table 7. Granger causality test results for 1965–2012 and 1990–2012.

Dependent variable	Independent variables (possible sources of causation)			ECT_{-1} coefficient (for possible long-run causality)
For Period 1: 1965–2012				
Model 1: VECM with GDP, FDI, and TML				
	ΔGDP	ΔFDI	ΔTML	ECT_{-1}
ΔGDP	–	1.02	4.04***	−0.053*
	[–]	[0.60]	[0.10]	(−11.1)
ΔFDI	0.65	–	3.91***	0.001
	[0.72]	[–]	[0.10]	(1.04)
ΔTML	1.52	0.23	–	0.04
	[0.47]	[0.89]	[–]	[2.49]
For Period 2: 1990–2012				
Model 1: VECM with GDP, FDI, and TML				
	ΔGDP	ΔFDI	ΔTML	ECT_{-1}
ΔGDP	–	8.79*	0.25	−0.37**
	[–]	[0.01]	[0.88]	(−5.51)
ΔFDI	5.09***	–	0.34	0.01
	[0.07]	[–]	[0.84]	(1.53)
ΔTML	0.52	1.68	–	−0.01
	[0.77]	[0.43]	[–]	[−0.36]
Model 2: VECM with GDP, FDI, and MOB				
	ΔGDP	ΔFDI	ΔMOB	ECT_{-1}
ΔGDP	–	8.99*	0.47	−0.001
	[–]	[0.01]	[0.79]	(−0.12)
ΔFDI	2.76	–	1.68	0.0001
	[0.25]	[–]	[0.43]	(0.73)
ΔMOB	0.35	0.21	–	−0.01*
	[0.83]	[0.90]	[–]	[−9.86]
Model 3: VECM with GDP, FDI, and INU				
	ΔGDP	ΔFDI	ΔINU	ECT_{-1}
ΔGDP	–	8.34**	1.25	−0.01
	[–]	[0.02]	[0.54]	(−0.43)
ΔFDI	2.97	–	1.96	0.001
	[0.23]	[–]	[0.38]	(0.68)
ΔINU	0.84	0.45	–	−0.295*
	[0.65]	[0.80]	[–]	[−10.4]
Model 4: VECM with GDP, FDI, and TII				
	ΔGDP	ΔFDI	ΔTII	ECT_{-1}
ΔGDP	–	9.02*	0.76	−0.39**
	[–]	[0.01]	[0.68]	(−5.67)
ΔFDI	4.40***	–	1.75	0.01
	[0.10]	[–]	[0.41]	(1.50)
ΔTII	4.04***	0.55	–	−0.01
	[0.10]	[0.76]	[–]	(−1.10)

Notes: GDP: per capita economic growth; FDI: foreign direct investment; TML: telephone landlines; MOB: mobile phones; INU: internet users; TII: telecommunications infrastructure index; VECM: vector error-correction model; ECT: error-correction term. Values in squared brackets represent probabilities for *F*-statistics. Values in parentheses represent *t*-statistics. Basis for the determination of long-run causality lies in the significance of the lagged ECT coefficient.
*, ** and *** Statistical significance at 1%, 5% and 10% respectively.

For 2001–2012 period. Model 1 during this sample period showed existence of bidirectional causality between economic growth and FDI [FDI ↕ GDP]. In Model 2, a unidirectional causality from FDI to economic growth [FDI ↓ GDP] was obtained. Model 2 also showed a unidirectional causality from economic growth to mobile phones [GDP ↓ MOB] and from FDI to mobile phones [FDI ↓ MOB]. In Model 3, a unidirectional causality

Table 8. Granger causality test results for 2001–2012.

Dependent variable	Independent variables (possible sources of causation)			ECT$_{-1}$ coefficient (for possible long-run causality)
Model 1: VECM with GDP, FDI, and TML				
	ΔGDP	ΔFDI	ΔTML	ECT$_{-1}$
ΔGDP	–	6.08**	3.50	−0.27***
	[–]	[0.05]	[0.17	(−3.65)
ΔFDI	4.81***	–	0.10	0.02
	[0.09]	[–]	[0.95]	(2.30)
ΔTML	0.95	1.47	–	−0.01
	[0.62]	[0.48]	[–]	[−0.20]
Model 2: VECM with GDP, FDI, and MOB				
	ΔGDP	ΔFDI	ΔMOB	ECT$_{-1}$
ΔGDP	–	4.65***	1.32	−0.004
	[–]	[0.09]	[0.52]	(−0.30)
ΔFDI	2.59	–	2.54	−0.01
	[0.27]	[–]	[0.28]	(−0.90)
ΔMOB	4.26***	4.81***	–	−0.05**
	[0.10]	[0.09]	[–]	[−6.83]
Model 3: VECM with GDP, FDI, and INU				
	ΔGDP	ΔFDI	ΔINU	ECT$_{-1}$
ΔGDP	–	5.99**	0.69	−0.03
	[–]	[0.05]	[0.71]	(−1.01)
ΔFDI	1.65	–	4.37**	0.02
	[0.44]	[–]	[0.10]	(0.85)
ΔINU	5.88**	4.69**	–	−0.12**
	[0.05]	[0.09]	[–]	[−8.47]
Model 4: VECM with GDP, FDI, and INS				
	ΔGDP	ΔFDI	ΔINS	ECT$_{-1}$
ΔGDP	–	7.10**	0.87	−0.35***
	[–]	[0.02]	[0.64]	(−3.85)
ΔFDI	4.15***	–	1.77	0.02
	[0.10]	[–]	[0.41]	(1.97)
ΔINS	1.33	1.19	–	−0.01
	[0.51]	[0.55]	[–]	[−0.07]
Model 5: VECM with GDP, FDI, and FBB				
	ΔGDP	ΔFDI	ΔFBB	ECT$_{-1}$
ΔGDP	–	5.01***	0.02	0.001
	[–]	[0.08]	[0.99]	(0.194)
ΔFDI	2.82	–	2.40	0.0003
	[0.24]	[–]	[0.30]	(1.04)
ΔFBB	0.16	0.47	–	−0.03**
	[0.92]	[0.79]	[–]	[−7.57]
Model 6: VECM with GDP, FDI, and TII				
	ΔGDP	ΔFDI	ΔTII	ECT$_{-1}$
ΔGDP	–	6.43**	1.93	−0.27***
	[–]	[0.04]	[0.38]	(−3.20)
ΔFDI	7.07**	–	7.02**	0.02
	[0.03]	[–]	[0.03]	(2.77)
ΔTII	7.60**	6.98**	–	0.009
	[0.02]	[0.03]	[–]	[1.37]

Notes: GDP: per capita economic growth; FDI: foreign direct investment; TML: telephone landlines; MOB: mobile phones; INU: internet users; INS: internet servers; FBB: fixed broadband; TII: telecommunications infrastructure index; VECM: vector error-correction model; ECT: error-correction term. Values in squared brackets represent probabilities for *F*-statistics. Values in parentheses represent *t*-statistics. Basis for the determination of long-run causality lies in the significance of the lagged ECT coefficient.

** and *** Statistical significance at 5% and 10% respectively.

Table 9. Summary of short-run Granger causality results.

Causal relationships tested in the model	FDI vs. GDP	TEL vs. GDP	FDI vs. TEL
Model 1: GDP–FDI–TML	Case 1: NC	Case 1: TML => GDP	Case 1: TML => FDI
	Case 2: FDI<=> GDP	Case 2: NC	Case 2: NC
	Case 3: FDI <=> GDP	Case 3: NC	Case 3: NC
Model 2: GDP–FDI–MOB	Case 1: NA	Case 1: NA	Case 1: NA
	Case 2: FDI => GDP	Case 2: NC	Case 2: NC
	Case 3: FDI => GDP	Case 3: MOB <= GDP	Case 3: FDI =>MOB
Model 3: GDP–FDI–INU	Case 1: NA	Case 1: NA	Case 1: NA
	Case 2: FDI => GDP	Case 2: NC	Case 2: NC
	Case 3: FDI => GDP	Case 3: INU <= GDP	Case 3: FDI <= INU
Model 4: GDP–FDI–INS	Case 1: NA	Case 1: NA	Case 1: NA
	Case 2: NA	Case 2: NA	Case 2: NA
	Case 3: FDI <=> GDP	Case 3: NC	Case 3: NC
Model 5: GDP–FDI–FBB	Case 1: NA	Case 1: NA	Case 1: NA
	Case 2: NA	Case 2: NA	Case 2: NA
	Case 3: FDI => GDP	Case 3: NC	Case 3: NC
Model 6: GDP–FDI–TII	Case 1: NA	Case 1: NA	Case 1: NA
	Case 2: FDI <=> GDP	Case 2: GDP => TII	Case 2: NC
	Case 3: FDI <=> GDP	Case 3: TII<= GDP	Case 3: FDI <=> TII

Notes: GDP: per capita economic growth; FDI: foreign direct investment; TML: telephone mainlines; MOB: mobile phones; INU: internet users; INS: internet servers; FBB: fixed broadband; TII: telecommunications infrastructure index; NA: not available for empirical investigation due to non-availability of data; NC: no causality.

from FDI to economic growth [FDI ↓ GDP] was observed. Additionally, this model also showed a unidirectional causality from internet users to FDI [INU ↓ FDI] and from economic growth to internet users [GDP ↓ INU]. Model 4 showed the existence of bidirectional causality between FDI and economic growth [FDI ↕ GDP], while Model 5 revealed the existence of unidirectional causality from FDI to economic growth [FDI ↓ GDP]. Finally, Model 6 showed existence of bidirectional causality between FDI and economic growth [FDI ↕ GDP] and telecommunications infrastructure [FDI ↕ TII]. Further, the model also showed unidirectional causality from economic growth to telecommunications infrastructure [GDP ↓ TII]. Notably, the finding of a unidirectional causality from economic growth to telecommunications infrastructure (in favor of DFH) is generally consistent with the results of Beil et al. (2005), Lee, Levendis, and Gutierrez (2012), Pradhan et al. (2016), Pradhan, Bele, and Pandey (2013b), and Shiu and Lam (2008a).

4.3.3. Generalized impulse response functions

Finally, to complement our analysis, we employed generalized impulse response functions to trace the effect of a one-off shock to one of the innovations on the current and future values of the endogenous variables. The generalized impulse responses offered additional insight into how shocks to variables capturing TEL, FDI, and economic growth impacted one another. These results are not reported in this article due to space constraints, but are available from the authors upon request.

5. Conclusion and policy implications

Scores of researchers have investigated the relationship between economic growth and FDI (stream A), while others have examined the link between economic growth and telecommunications infrastructure/usage (stream B). By contrast, this paper investigates the causal relationships between economic growth, FDI, and telecommunications infrastructure and its usage – all simultaneously. Using panel data on Asian-21 countries from 1965 to 2012, we found that telecommunications infrastructure/usage, FDI, and economic growth appeared to be cointegrated. The panel Granger causality test further confirmed that FDI and telecommunications infrastructure/usage are general long-run causes for economic growth. However, our short-run causality results revealed a wide range of short-run adjustment dynamics between the variables including the possibility of feedback between them in several instances.

As is evident from our results, considering steams A and B separately lead to potentially biased results. Our paper therefore clearly illuminates previous research, contradicts some, and supports others. It also plainly distinguishes between short-run and long-run results – which often receives no attention in the results of the previous studies.

On the policy front, close linkages between telecommunication infrastructure development/usage, FDI, and economic growth show that the Asian-21 countries wishing to sustain economic growth in the long run should focus attention in developing their telecommunication infrastructure, ensuring greater adoption of new information and communication technologies (ICTs), as well putting in place policies that promote inflows of FDI.

Improvement in the telecommunication infrastructure and strategies to increase adoption of modern ICTs in the 21 Asian countries would lead to a number of positive spill-overs effects that will potentially enhance FDI flows and elevate economic growth in these countries. The spill-over effects include the following benefits: firms are able to enhance their competitiveness by globalizing their businesses (Hof, 2005); improve their firm-level productivity (Entner, 2008; Sadun & Farooqui, 2006); increase transparency in corporate governance and bring public sector efficiency via e-governance systems (Kalam, 2003); improve access to education and healthcare services (Bhatnagar, 2000); foster creative learning environment for an innovation-driven economy (Crosling, Nair, & Vaithilingam, 2015); and enhance employment opportunities and increase income levels for the stakeholders (Katz, 2012; Nair & Vaithilingam, 2013).

The above-mentioned spill-over benefits powered by improvement in the ICT ecosystem will enable the 21 Asian countries to move up the global knowledge and innovation value chain, which is consistent with the central propositions of the endogenous growth theory proposed by Romer (1986, 1990). This in return will raise the rate of return and value creation opportunities for foreign investors, increasing the quality and quantity of FDI inflows to these countries. The FDI inflows will reinforce the development of the ICT ecosystem, further propelling economic growth in the Asian economies that were considered in this paper.

Notes

1. See also Arvin and Pradhan's (2014) investigation relating to the causal relationships between broadband penetration, degree of urbanization, foreign direct investment, and economic growth using a panel data set covering the G-20 countries. The present study instead concentrates on the telecommunications infrastructure and usage generally and its association with economic growth and foreign direct investment in Asian countries.
2. The adoption of telecommunications technology from abroad and inflows of FDI have links on obvious and intuitive grounds.

3. TII is constructed using PCA. PCA linearly transforms the variables so that they are orthogonal to each other (Lewis-Beck, 1994). It is ideally suited because it maximizes the variance, rather than minimizing the least square distance. In sum, PCA transforms the data into new variables (i.e. principal components) so that they are not correlated. This approach is described in most textbooks and is used in several articles including Pradhan, Arvin, Norman, et al. (2014) and Pradhan et al. (2013b). The approach is outlined in Appendix B.

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Appendix A: The Asian-21 panel of countries

The Asian-21 countries comprise of Bangladesh, India, China, Hong Kong, Indonesia, Iraq, Iran, Israel, Japan, Kuwait, Malaysia, the Philippines, Pakistan, Qatar, Saudi Arabia, Singapore, South Korea, Sri Lanka, Thailand, the United Arab Emirates, and Vietnam. The countries were chosen based on the data availability over the period 1965–2012.

Appendix B: Formulation of Composite Index of Telecommunications Infrastructure Index using PCA

We constructed a composite index of telecommunications infrastructure (TII). The index was obtained through principal component analysis using following three steps: (1) data were arranged in order to create an input matrix for principal components, thereafter the matrix was normalized based on the min-max method; (2) using the principal component analysis, Eigen-values, factor loadings, and principal components were derived; and (3) the principal components were used to construct the TII for each country for each year. The approach of constructing the composite index is described in most textbooks and is used in several past studies (e.g. Pradhan, Mukhopadhyay, Gunashekar, Samadhan, & Pandey, 2013; Pradhan, Arvin, Bahmani, & Norman, 2014). The variables included for this TII were telephone landlines (TML), mobile phones (MOB), and internet users (INU) for the duration 1993–2012. TII for the duration 2001–2012 involved TML, MOB, INU, internet servers (INS), and fixed broadband (FBB) variables. Tables B1 and B2 present the statistical values from our principal component analysis.

Table B1. The summary of PCA-related information for Telecommunications Infrastructure Index (TII), 1993–2012.

Sl. numbers	Eigen-value	Proportion variance	Cumulative
Part A: Eigen analysis of correlation matrix			
PCs	Eigen-value	Proportion	Cumulative
1	2.382	0.794	0.794
2	0.546	0.182	0.976
3	0.072	0.024	1.000
Part B: Eigen vectors (component loadings)			
Variables	PC1	PC2	PC3
TML	0.498	0.867	0.023
MOB	0.611	−0.369	0.700
INU	0.615	−0.334	−0.714

Notes: PCs: principal components;
TML: telephone landlines; MOB: mobile phones; and INU: internet users.

Table B2. The summary of PCA-related information for TII, 2001–2012.

Sl. numbers	Eigen-value	Proportion variance	Cumulative	
Part A: Eigen analysis of correlation matrix				
PCs	Eigen-value	Proportion	Cumulative	
1	4.039	0.808	0.808	
2	0.529	0.106	0.914	
3	0.215	0.043	0.957	
4	0.489	0.024	0.981	
5	0.098	0.019	1.000	

Part B: Eigen vectors (component loadings)					
Variables	PC1	PC2	PC3	PC4	PC5
TML	0.395	−0.797	−0.318	−0.218	−0.243
MOB	0.432	0.587	−0.329	−0.478	−0.362
INU	0.478	0.031	−0.035	−0.159	0.863
INS	0.455	−0.035	0.859	−0.052	−0.226
FBB	0.971	0.132	−0.225	0.834	−0.121

Notes: PCs: principal components;
TML: telephone landlines; MOB: mobile phones; INU: internet users; INS: internet servers; and FBB: fixed broadband.