Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 00 (2018) 000–000

Transportation Research Procedia

www.elsevier.com/locate/procedia

World Conference on Transport Research - WCTR 2019 Mumbai 26-31 May 2019

The Long Relationships between ICT Infrastructure, Urbanization, Transportation and Economic Growth

Rudra P. Pradhan[a]*

[a]Indian Institute of Technology, Kharagpur, India

Abstract

Information and communication technology (ICT) infrastructure plays an important role in the efficient function functioning of a transport sector and its presence has become one of the key objectives of the economic development. The study brings the interfaces ICT infrastructure, transportation, urbanization and economic growth in the G-20 countries between 1961 and 2016. The emphasis is to know the causality between these variables, one way, both ways, or not at all. The empirical results show that ICT infrastructure, transportation and urbanization causes economic growth in the G-20 countries.

Peer-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY.

Keywords: ICT infrastructure, transportation, urbanization, economic growth, G-20 countries

1. Introduction

The transportation-economic growth nexus is among the major important issues addressed in the development literature. The majority of the empirical studies demonstrate the positive impact of transportation on economic growth and unveil that transport plays a vital role in economic activity either directly or as a component to other factors of production (see, for instance, Saidi et al., 2018; Achour and Belloumi, 2016; Hakim and Merkert, 2016; Loo and

* Corresponding author. Tel.: +919733742104; fax: +91-3222278027.
E-mail address: rudrap@vgsom.iitkgp.ernet.in

Peer-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY

Banister, 2016; Farhadi, 2015; Pradhan and Bagchi, 2013; Chi and Beck, 2013; Button and Yuan, 2013; Meersman and Van de Voorde, 2013; Chi and Baek, 2013; Kayode et al., 2013; Ding, 2013; Banister, 2012;Yao and Yang, 2012; Yu et al., 2012; Marazzo et al., 2010; Khadaroo and Seetanah, 2008; Yamaguchi, 2007; Kasarda and Green, 2005; Hong et al., 2011; Wang, 2002; Jiang, 2001; Phang, 2003; Njoh, 2000; Fernald, 1999; Gillen, 1996; Linneker and Spence, 1996; WDR, 1994; Munnell, 1992; Aschauer, 1989). However, in this paper, we look for direction of causality between transportation and economic growth. We also look for the impact of information and communication technology (ICT) infrastructure and urbanization on transportation-economic growth nexus. Empirically, production function approach is frequently used to examine the linkage and in maximum occasions, the impact is observed from transport infrastructure to economic growth. However, in reality, there is feasibility of feedback relationship between the two. Additionally, development literature supports that both ICT infrastructure and urbanization are the important factors that can affect the nexus between transportation and economic growth.

2. Literature Review

The objective of the paper is to know the direction of causality among ICT infrastructure, urbanization, transportation and economic growth. Here we present three strands of literature, relating to economic growth.

The first strand of literature is between transport infrastructure and economic growth. There can be four equally possible complementary hypotheses between the two: the *supply-leading hypothesis* (SLH^1) of transportation infrastructure-economic growth nexus, where transport infrastructure Granger causes economic growth; the *demand-following hypothesis* (*DF*H^1) of transport infrastructure-economic growth nexus, where economic growth Granger causes transport infrastructure; third, the *feedback hypothesis* (FBH^1) of transport infrastructure-economic growth nexus, suggests that both transport infrastructure and economic growth Granger cause each other; and the *neutrality hypothesis* (NEH^1) of transport infrastructure-economic growth nexus, where both transport infrastructure and economic growth do not Granger cause each other. Pradhan and Bagchi (2013) provides the brief summary of the studies where we find the support of these four hypotheses.

The second strand is between ICT infrastructure and economic growth. There can be four equally possible complementary hypotheses between the two: the *supply-leading hypothesis* (SLH^2) of ICT-economic growth nexus,

where ICT infrastructure Granger causes economic growth; the *demand-following hypothesis* (*DF*H^2) of ICT-economic growth nexus, where economic growth Granger causes ICT infrastructure; third, the *feedback hypothesis* (FBH^2) of ICT-economic growth nexus, suggests that both ICT infrastructure and economic growth Granger cause each other; and the *neutrality hypothesis* (NEH^2) of ICT-economic growth nexus, where both ICT infrastructure and economic growth do not Granger cause each other. Pradhan et al. (2016) provides the brief summary of various studies where we find the support of these four hypotheses.

The third strand of literature is between urbanization and economic growth. There can be four equally possible complementary hypotheses between the two: the *supply-leading hypothesis* (SLH^3) of urbanization-economic growth nexus, where urbanization Granger causes economic growth; the *demand-following hypothesis* (*DF*H^3) of urbanization-economic nexus, where urbanization Granger causes economic growth; third, the *feedback hypothesis* (FBH^3) of urbanization-economic growth nexus, suggests that both urbanization and transportation infrastructure Granger cause each other; and the *neutrality hypothesis* (NEH^3) of urbanization-economic growth nexus, where both urbanization and economic growth do not Granger cause each other. To the best of our knowledge, there is scarcity of literature that support these four hypotheses.

2. Hypotheses, Data, Variables, and Empirical Model

This study looks to test the following hypotheses:

H_{1A}: Transportation (TRA) Granger causes economic growth (PEG). This is named TRA-led PEG hypothesis.

H_{2A}: ICT infrastructure (ICT) Granger causes economic growth. This is named ICT-led PEG hypothesis.

H_{3A}: Urbanization (URB) Granger causes economic growth. This is termed URB-led TRA hypothesis.

H_{4A}: ICT infrastructure (ICT) Granger causes transportation (TRA). This is named ICT-led TRA hypothesis.

H_{5A}: ICT infrastructure (ICT) Granger causes urbanization. This is named ICT-led PEG hypothesis.

H_{6A}: Urbanization (URB) Granger causes transportation. This is termed URB-led TRA hypothesis.

Figure 1 presents the details of these six hypotheses.

The study uses annual data from 1961 to 2016[†] for *G-20* countries were obtained from the *World Development Indicators* of the World Bank. The G-20 contains 19 member countries and the European Union. Thus, though we look at the G-20, within this group of both developed and emerging economies, we observe only 19 member countries, which are used for this investigation. This group has two divisions, based on the World Bank purchasing power parity of their per capita income. First, the developing group of G-20, which entails Argentina, Brazil, China, India, Indonesia, Mexico, the Russian Federation, Saudi Arabia, South Africa, and Turkey. Second, the developed group of G-20, which entails Australia, Canada, France, Germany, Italy, Japan, the Korean Republic, the United Kingdom, and the United States.

This study uses the following variables: telephone land lines (TEL), mobile phones (MOB), internet users (INU), internet servers (INS), and fixed broadband (FIB), goods carried by air transport (GAT), passengers carried by air transport (PAT), goods carried by railways (GRA), passengers carried by railways (PRA), rain lines (RAL), urbanization (URB), and per capita economic growth (PEG).

The study also uses two composite indices, namely, composite index of ICT infrastructure (CIC) and composite index of transport infrastructure (CIT). CIC is the weighted average five different indicators of ICT infrastructure, while CIT is the weighted average of five different transport infrastructure indicators. We use principal component analysis (PCA) to have these two indices. The detailed description of this index formulation is available in Pradhan et al. (2015). The study considers five specifications and six cases, covering different indicators of ICT infrastructure and transportation. The following vector error correction model (VECM) is deployed to investigate the possible directions of causality among ICT infrastructure, urbanization, transportation and economic growth.

[†] It involves unbalanced panel since data on these variables is not uniformly available for all countries and for all the years during the study period.

$$\begin{bmatrix} \Delta \ln PEG_{it} \\ \Delta TRA_{it} \\ \Delta \ln ICT_{it} \\ \Delta \ln URB \end{bmatrix} = \begin{bmatrix} \alpha_{1j} \\ \alpha_{2j} \\ \alpha_{3j} \\ a_{4j} \end{bmatrix} + \sum_{k=1}^{m} \begin{bmatrix} \mu_{11ik}(L)\mu_{12ik}(L)\mu_{13ik}(L)\mu_{14ik}(L) \\ \mu_{21ik}(L)\mu_{22ik}(L)\mu_{23ik}(L)\mu_{24ik}(L) \\ \mu_{31ik}(L)\mu_{32ik}(L)\mu_{33ik}(L)\mu_{34ik}(L) \\ \mu_{41ik}(L)\mu_{42ik}(L)\mu_{43ik}(L)\mu_{44ik}(L) \end{bmatrix} \begin{bmatrix} \Delta \ln PEG_{it-k} \\ \Delta \ln TRA_{it-k} \\ \Delta \ln ICT_{it-k} \\ \Delta \ln URB_{it-k} \end{bmatrix} + \begin{bmatrix} \delta_{1i} ECT_{it-1} \\ \delta_{2i} ECT_{it-1} \\ \delta_{3i} ECT_{it-1} \\ \delta_{4i} ECT_{it-1} \end{bmatrix} \begin{bmatrix} \xi_{1it} \\ \xi_{2it} \\ \xi_{3it} \\ \xi_{4it} \end{bmatrix} \quad \textbf{(1)}$$

where *i* is the country specification; *t* is the time specification; and ε is the error term.

ECT_{-1} is lagged error-correction term, which represents the long-run dynamics among the variables. However, the inclusion of ECT in the model depends upon the specification of the time series variables, which need to be integrated of order one (I (1)) and cointegrated. The null hypotheses of this study are to test the followings:

H_{1A}: $\mu_{12ik} \neq 0$; $\mu_{13ik} \neq 0$; $\mu_{14ik} \neq 0$; and $\delta_{1i} \neq 0$ **for k = 1, 2, 3, ..., m**

H_{1B}: $\mu_{21ik} \neq 0$; $\mu_{23ik} \neq 0$; $\mu_{24ik} \neq 0$; and $\delta_{2i} \neq 0$ **for k = 1, 2, 3, ..., m**

H_{1C}: $\mu_{31ik} \neq 0$; $\mu_{32ik} \neq 0$; $\mu_{13ik} \neq 0$; and $\delta_{3i} \neq 0$ **for k = 1, 2, 3, ..., m**

For knowing the direction of causality between these variables. For example, in the first occasion, transportation, ICT infrastructure and urbanization can cause economic growth, if μ_{12ik} and μ_{13ik}, and μ_{14ik} are significantly different from zero.

3. Empirical Results and Discussion

The study starts with reporting order of integration and cointegration among ICT infrastructure, urbanization,

transportation and economic growth.

The panel unit root tests are used at three levels to examine the order of integration of the variables, while Pedroni panel cointegration is used to know the existence of cointegration between them in the panel setting. The estimated results confirm that all the variables are integrated of order one and having cointegration among them. This is accurate for all the six specifications and six cases in each specification, depending upon the inclusion of different ICT infrastructure and transportation indicators.

The above findings allow us to apply VECM to examine the Granger causal relationships among these three variables. The results of VECM are not reported here due to space constraints.

The study first targets the long-run results, discovered by examining the statistical significance of the ECT-1 coefficients. The estimated results show that when ΔPEG is the dependent variable, the coefficients are statistically significant at a 1% level. This implies that economic growth tends to converge to its long-run equilibrium path in response to change in ICT infrastructure, transportation and urbanization. This is true for all the six specifications and six cases that we consider for this investigation process (see Table 1). Therefore, the overall conclusion is that economic growth in G-20 countries is significantly influenced by ICT infrastructure, transportation and urbanization. In other words, to excite economic growth, the requirement is to enhance ICT infrastructure, transportation and urbanization in the G-20 countries. In the short run, however, the results are mostly non-uniform and varies specification to specification and case to case within a particular case (see Table 2).

4. Conclusion

The study aims to examine causal relationships between ICT infrastructure, urbanization, transportation and economic growth simultaneously. We find that they are cointegrated, indicating the existence of long-run relationship. Most importantly, there is clear evidence that ICT infrastructure, urbanization and transportation matter in the determination of long-run economic growth. The empirical results suggest that to stimulate economic growth in the G-20 countries, policy-makers should give priority to ICT infrastructure, urbanization and transportation in the economy.

Appendix A: G-20 Profile

Table A. 1. Macroeconomic Profiles of the G-20 Countries

Countries	POP	GDP^{+}	GDP^{++}	$PGDP^{+}$	$PGDP^{++}$	TT	HDI
G-20 Developed Countries							
Australia	24.3	1.26	1.19	51850	48899	0.50	0.939
Canada	36.2	1.53	1.68	42210	46437	0.95	0.920
France	64.6	2.46	2.73	38128	42314	1.21	0.897
Germany	82.7	3.47	3.98	41902	48111	2.87	0.926
Italy	60.7	1.85	2.23	30507	36833	0.95	0.887
Japan	126.9	4.94	5.24	38917	41275	1.52	0.903
Korean Republic	51.2	1.41	1.93	27539	37740	1.17	0.901
United Kingdom	65.6	2.63	2.79	40096	42481	1.19	0.909
United States	323.3	18.6	18.6	57436	57436	3.94	0.920
G-20 Developing Countries							
Argentina	43.6	0.55	0.87	12503	20047	0.14	0.827
Brazil	206.1	1.80	3.14	8727	15242	0.48	0.754
China	1382.7	11.2	21.3	8113	15399	4.20	0.738
India	1346.3	2.26	10.7	1723	7716	0.85	0.624
Indonesia	258.7	0.93	3.03	3604	11720	0.35	0.689
Mexico	122.2	1.05	2.32	8555	18938	0.81	0.762
Russian Federation	146.9	1.52	4.15	10630	28918	0.84	0.804
Saudi Arabia	31.7	0.64	1.75	20150	55158	0.52	0.847
South Africa	55.9	0.29	0.74	5261	13225	0.20	0.666
Turkey	79.82	0.86	1.99	10743	24912	0.42	0.767

Note 1: POP is population; GDP is gross domestic product; PGDP is per capita gross domestic product; PPP is purchasing power parity; TT is total trade; and HDI is human development index.

Note 2: POP is in millions; GDP^{+} is in trillion USD; GDP^{++} is in trillion USD; $PCGDP^{+}$ is in USD; $PCGDP^{++}$ is in USD; TT is in trillion USD; and HDI figure is in number.

Note 3: $^{+}$ stands GDP and PGDP in PPP; and $^{++}$ stands GDP and PGDP in nominal.

References

Achour, H., and Belloumi, M. (2016). Investigating the Causal Relationship between Transport Infrastructure, Transport Energy Consumption and Economic Growth in Tunisia. *Renewable and Sustainable Energy Reviews*, *56*, 988-998.

Aschauer, D. A. (1989). Public Investment and Productivity Growth in the Group of Seven. Economic Perspectives, 13, 17-25.

Banister, D. (2012). Transport and Economic Development: Reviewing the Evidence. *Transport Reviews: A Transnational Transdisciplinary Journal*, 32(1): 1-2.

Button, K. and Yuan, J. (2013). Airfreight Transport and Economic Development: An Examination of Causality. *Urban Studies*, *50*(2), 329-340.

Chi, J. and Baek, J. (2013). Dynamic Relationship between Air Transport Demand and Economic Growth in the United States: A New Look. *Transport Policy*, *29*, 257-260.

Deng, T., Shao, S., Yang, L. and Zhang, X. (2014). Has the Transport-Led Economic Growth Effect Reached a Peak in China? A Panel Threshold Regression Approach. *Transportation*, 41(3): 567-587.

Ding, C. (2013). Transport Development, Regional Concentration and Economic Growth. *Urban Studies*, *50* (2): 312-328.

Farhadi, M. (2015). Transport infrastructure and long-run economic growth in OECD countries. *Transportation Research Part A: Policy and Practice*, *74*, 73-90.

Fernald, J. G. (1999). Roads to prosperity? Assessing the link between public capital and productivity. The American Economic Review. 89: 619-638.

Gillen, D. W. (1996). Transportation Infrastructure and Economic Development: A Review of Recent Literature. *Logistics and Transportation Review*, 32 (1): 39-62.

Hakim, M. M. and Merkert, R. (2016). The Causal Relationship between Air Transport and Economic Growth: Empirical Evidence from South Asia. *Journal of Transport Geography*, *56*, 120-127.

Hong, J., Chu, Z. and Wang, Q. (2011). Transport Infrastructure and Regional Economic Growth: Evidence from China. *Transportation*, 38 (5), 737-752.

Jiang, B. (2001). A Review of Studies on the Relationship between Transport Infrastructure Investments and Economic Growth. Canada Transportation Act Review, British Columbia, Vancouver.

Kasarda, J. D. and Green, J. D. (2005). Air Cargo as an Economic Development Engine: A Note on Opportunities and Constraints. *Journal of Air Transport Management*, 11 (6): 459-462.

Kayode, O., Babatunde, O. and Abiodun, F. (2013). An Empirical Analysis of Transport Infrastructure Investment and Economic Growth in Nigeria. *Social science*, *2*(6): 179-188.

Khadaroo, J. and Seetanah, B. (2008). Transport and Economic Performance: The Case of Mauritius. Journal of Transport Economics and Policy, 42(2): 255-267.

Linneker, B. and Spence, N. (1996). Road Transport Infrastructure and Regional Economic Development: The Regional Development Effects of the M25 London Orbital Motorway. *Journal of Transport Geography*, *4*(2): 77-92.

Loo, B. P. and Banister, D. (2016). Decoupling Transport from Economic Growth: Extending the Debate to Include Environmental and Social Externalities. *Journal of Transport Geography*, *57*, 134-144.

Marazzo, M., Scherre, R. and Fernandes, E. (2010). Air Transport Demand and Economic Growth in Brazil: A Time Series Analysis. *Transportation Research Part E: Logistics and Transportation Review*, *46*(2): 261-269.

Meersman, H. and Van de Voorde, E. (2013). The Relationship between Economic Activity and Freight Transport. In *Freight Transport Modelling Emerald Group Publishing Limited*, 15-43.

Munnell, A. H. (1992). Infrastructure Investment and economic Growth. Journal of Economic Perspectives. 6, 189-198.

Nakamura, H. (2000). The Economic Evaluation of Transport Infrastructure: Needs for International Comparisons. *Transport Policy*, *7*(1): 3-6.

Njoh, A. J. (2000). Transportation Infrastructure and Economic Development in Sub-Saharan Africa. *Public Works Management and Policy*, *4*(4): 286-296.

Oster, C. V., Rubin, B. M. and Strong, J. S. (1997). Economic Impacts of Transportation Investments: The Case of Federal Express. *Transportation Journal*, *37*(2): 34-44.

Phang, S. (2003). Strategic Development of Airport and Rail Infrastructure: The Case of Singapore. *Transport Policy*, 10: 27-33.

Pradhan, R.P. and Bagchi, T. P. (2013). Effect of Transportation Infrastructure on Economic Growth in India: The VECM Approach. Research in Transportation Economics, 38: 139-148.

Pradhan, R. P., Arvin, M. B., Mittal, J., and Bahmani, S. (2016). Relationships between telecommunications infrastructure, capital formation, and economic growth. *International Journal of Technology Management*, 70 (2-3): 157-176.

Wang, E. C. (2002). Public Infrastructure and Economic Growth: A New Approach Applied to East Asian Economies. *Journal of Policy Modelling*, 24, 411-435.

WDR (1994). World Development Report, World Bank. Oxford University Press, Oxford.

Yamaguchi, K. (2007). Inter-Regional Air Transport Accessibility and Macro-Economic Performance in Japan. *Transportation Research Part E: Logistics and Transportation Review*, *43*(3): 247-258.

Yao, S. and Yang, X. (2012). Air Transport and Regional Economic Growth in China. *Asia-Pacific Journal of Accounting & Economics*, *19* (3): 318-329.

Yu, N., De Jong, M., Storm, S. and Mi, J. (2012). Transport Infrastructure, Spatial Clusters and Regional Economic Growth in China. *Transport Reviews*, *32*(1): 3-28.

Table 1. Results of Panel Granger Causality Test

Specification 1: PEG, TRA, TEL, URB

Case 1

Dependent Variable	Independent variables and ECT$_{-1}$			
	ΔPEG	ΔGAT	ΔTEL	URB	ECT$_{-1}$
ΔPEG	------	5.98*	0.68	12.2*	-0.77*
ΔTRA	2.39	------	7.61*	11.3*	-0.04
ΔTEL	5.34*	0.74	------	13.3*	-0.001
ΔURB	4.48**	1.06	0.63	------	-0.001

Case 2

	ΔPEG	ΔPAT	ΔTEL	URB	ECT$_{-1}$
ΔPEG	------	18.2*	0.38	14.0*	-0.74*
ΔTRA	4.98**	------	0.39	12.2*	-0.10
ΔTEL	6.16*	2.34	------	14.5*	-0.01
ΔURB	7.23*	3.59	0.60	------	-0.001

Case 3

	ΔPEG	ΔGRA	ΔTEL	URB	ECT$_{-1}$
ΔPEG	------	5.29*	0.61	10.2*	-0.59*
ΔTRA	1.04	------	0.76	3.99	-0.04
ΔTEL	6.26*	2.62	------	8.60*	-0.01
ΔURB	7.25*	4.41**	2.91	------	-0.001

Case 4

	ΔPEG	ΔPRA	ΔTEL	URB	ECT$_{-1}$
ΔPEG	------	5.22*	0.34	4.98**	-0.59*
ΔTRA	0.85	------	0.52	5.09*	-0.01
ΔTEL	5.55**	2.97	------	8.53*	-0.004
ΔURB	9.50*	0.41	3.79	------	-0.34

Case 5

	ΔPEG	ΔRAL	ΔTEL	URB	ECT$_{-1}$
ΔPEG	------	0.16	0.22	5.68*	-0.64*
ΔTRA	4.67**	------	0.01	5.15*	-0.003
ΔTEL	5.78*	2.35	------	0.79	-0.01
ΔURB	17.5*	1.18	2.77	------	-0.001

Case 6

	ΔPEG	ΔCIT	ΔTEL	URB	ECT$_{-1}$
ΔPEG	------	13.8*	1.25	4.96**	-0.77*
ΔTRA	3.51	------	0.76	18.4*	-0.04
ΔTEL	4.63**	1.20	------	4.45**	-0.02
ΔURB	16.8*	5.20*	2.53	------	-0.001

Specification 2: PEG, TRA, MOB, URB

Case 1

	ΔPEG	ΔGAT	ΔMOB	URB	ECT$_{-1}$
ΔPEG	------	2.70	12.4*	8.41*	-0.81
ΔTRA	5.17*	------	1.63	6.12*	-0.08
ΔMOB	0.86	5.46*	------	2.99	-0.07
ΔURB	12.4*	1.17	21.6*	------	-0.001

Case 2

	ΔPEG	ΔPAT	ΔMOB	URB	ECT$_{-1}$
ΔPEG	------	20.4*	6.49*	5.46*	-0.76*
ΔTRA	5.50*	------	0.08	10.5*	-0.11
ΔMOB	8.10*	4.15**	------	6.67*	-0.20
ΔURB	9.66*	0.62	17.3*	------	-0.003

Case 3

	ΔPEG	ΔGRA	ΔMOB	URB	ECT$_{-1}$
ΔPEG	------	14.4*	9.36*	4.74**	-0.10
ΔTRA	1.46	------	3.21	3.27	-0.001
ΔMOB	9.82*	1.00	------	1.96	-0.17
ΔURB	0.01	3.02	0.86	------	-0.01

Case 4

	ΔPEG	ΔPRA	ΔMOB	URB	ECT$_{-1}$
ΔPEG	------	0.31	7.37*	6.88*	-0.16*
ΔTRA	10.7*	------	2.88	2.22	-0.01
ΔMOB	11.4*	0.003	------	0.41	-0.22
ΔURB	0.05	0.23	0.76	------	-0.001

Case 5

	ΔPEG	ΔRAL	ΔMOB	URB	ECT$_{-1}$
ΔPEG	------	0.35	7.16*	4.95*	-0.21*
ΔTRA	9.58*	------	1.58	5.27*	-0.01
ΔMOB	16.2*	2.09	------	4.56**	-0.26
ΔURB	2.94	0.30	2.81	------	-0.001

Case 6

	ΔPEG	ΔCIT	ΔMOB	URB	ECT$_{-1}$
ΔPEG	------	5.74*	4.90**	0.25	-0.15*
ΔTRA	1.34	------	6.08*	13.1*	-0.01*
ΔMOB	4.50**	2.37	------	6.07*	-0.31*
ΔURB	0.52	1.47	7.51*	------	-0.01

Specification 3: PEG, TRA, INU, URB

Case 1

	ΔPEG	**ΔGAT**	**ΔINU**	**URB**	**ECT$_{-1}$**
ΔPEG	------	12.7*	1.15	0.30	-0.10*
ΔTRA	1.50	------	7.92*	4.39**	-0.01
ΔINU	5.63*	0.98	------	6.32*	-0.08
ΔURB	21.0*	5.35*	5.94*	------	-0.03

Case 2

	ΔPEG	**ΔPAT**	**ΔINU**	**URB**	**ECT$_{-1}$**
ΔPEG	------	12.4*	21.9*	1.87	-0.54*
ΔTRA	0.93	------	18.3*	6.23*	-0.08
ΔINU	33.1*	19.4*	------	0.59	-0.46
ΔURB	19.0*	4.60**	5.88*	------	-0.05

Case 3

	ΔPEG	**ΔGRA**	**ΔINU**	**URB**	**ECT$_{-1}$**
ΔPEG	------	17.4*	2.04	5.53*	-0.20*
ΔTRA	1.02	------	0.32	0.43	-0.02
ΔINU	9.22*	4.58**	------	0.52	-0.23
ΔURB	0.61	1.64	7.02*	------	-0.01

Case 4

	ΔPEG	**ΔPRA**	**ΔINU**	**URB**	**ECT$_{-1}$**
ΔPEG	------	0.32	2.09	6.12*	-0.10*
ΔTRA	14.0*	------	0.25	1.21	-0.02
ΔINU	10.3*	4.89**	------	2.32	-0.17
ΔURB	0.85	0.19	5.59*	------	-0.10

Case 5

	ΔPEG	**ΔRAL**	**ΔINU**	**URB**	**ECT$_{-1}$**
ΔPEG	------	0.20	10.9*	5.61*	-0.09*
ΔTRA	6.22*	------	0.46	3.31	-0.02
ΔINU	31.2*	5.03**	------	1.22	-0.29
ΔURB	1.10	0.01	11.2*	------	-0.01

Case 6

	ΔPEG	**ΔCIT**	**ΔINU**	**URB**	**ECT$_{-1}$**
ΔPEG	------	5.09**	0.30	4.59*	-0.02*
ΔTRA	0.83	------	5.23*	8.50*	-0.01
ΔINU	9.54*	1.07	------	0.09	-0.29
ΔURB	0.48	4.74**	12.8	------	-0.01

Specification 4: PEG, TRA, INS, URB

Case 1

	ΔPEG	**ΔGAT**	**ΔINS**	**URB**	**ECT$_{-1}$**
ΔPEG	------	6.19*	1.02	20.7*	-0.68*
ΔTRA	3.62	------	7.42*	0.60	-0.08
ΔINS	11.9*	0.89	------	6.56*	-0.23
ΔURB	1.65	0.17	2.18	------	-0.01

Case 2

	ΔPEG	**ΔPAT**	**ΔINS**	**URB**	**ECT$_{-1}$**
ΔPEG	------	3.83	0.55	18.5*	-0.67*
ΔTRA	6.15*	------	0.13	5.66*	-0.03
ΔINS	12.5*	0.49	------	5.85*	-0.28
ΔURB	1.37	1.40	2.27	------	-0.01

Case 3

	ΔPEG	**ΔGRA**	**ΔINS**	**URB**	**ECT$_{-1}$**
ΔPEG	------	5.09**	0.32	17.5*	-0.77*
ΔTRA	0.12	------	0.63	0.04	-0.05
ΔINS	9.30*	2.19	------	5.96*	-0.32
ΔURB	0.63	4.83**	2.03	------	-0.02

Case 4

	ΔPEG	**ΔPRA**	**ΔINS**	**URB**	**ECT$_{-1}$**
ΔPEG	------	5.33*	0.52	17.5*	-0.75*
ΔTRA	4.97**	------	0.05	0.72	-0.01
ΔINS	10.6*	1.28	------	5.66*	-0.35
ΔURB	0.51	0.23	2.02	------	-0.01

Case 5

	ΔPEG	**ΔRAL**	**ΔINS**	**URB**	**ECT$_{-1}$**
ΔPEG	------	5.60**	0.67	20.8*	-0.80*
ΔTRA	2.90	------	0.90	0.62	-0.01
ΔINS	8.13*	0.68	------	5.58*	-0.26
ΔURB	0.86	0.01	3.31	------	-0.01

Case 6

	ΔPEG	**ΔCIT**	**ΔINS**	**URB**	**ECT$_{-1}$**
ΔPEG	------	4.98**	0.30	11.3*	-0.57*
ΔTRA	1.64	------	0.14	1.16	-0.07
ΔINS	9.07*	1.33	------	5.51*	-0.48
ΔURB	0.58	2.52	2.08	------	-0.04

Specification 5: PEG, TRA, FIB, URB

Case 1

	ΔPEG	ΔGAT	ΔFIB	URB	ECT$_{-1}$
ΔPEG	------	4.97**	13.3*	14.8*	-0.71
ΔTRA	2.29	------	0.75	2.42	-0.04
ΔFIB	4.93**	0.11	------	2.55	-0.31
ΔURB	0.39	0.52	3.80	------	-0.01

Case 2

	ΔPEG	ΔPAT	ΔFIB	URB	ECT$_{-1}$
ΔPEG	------	5.23*	12.6*	10.8*	-0.48*
ΔTRA	2.75	------	0.45	6.74*	-0.04
ΔFIB	11.0*	2.38	------	7.44*	-0.47
ΔURB	0.12	0.10	2.52	------	-0.01

Case 3

	ΔPEG	ΔGRA	ΔFIB	URB	ECT$_{-1}$
ΔPEG	------	5.15**	10.8*	10.0*	-0.64*
ΔTRA	0.69	------	4.85**	0.08	-0.05
ΔFIB	7.81*	0.19	------	5.89*	-0.38
ΔURB	0.44	0.17	3.29	------	-0.01

Case 4

	ΔPEG	ΔPRA	ΔFIB	URB	ECT$_{-1}$
ΔPEG	------	2.10	0.89	20.9*	-0.30*
ΔTRA	8.04*	------	0.06	0.22	-0.01
ΔFIB	6.58*	0.64	------	2.72	-0.18
ΔURB	0.38	0.02	3.08	------	-0.01

Case 5

	ΔPEG	ΔRAL	ΔFIB	URB	ECT$_{-1}$
ΔPEG	------	0.07	7.54*	8.58*	-0.46*
ΔTRA	12.1*	------	0.63	1.66	-0.01
ΔFIB	13.8*	8.48*	------	9.41*	-0.37
ΔURB	3.22	0.04	5.61*	------	-0.01

Case 6

	ΔPEG	ΔCIT	ΔFIB	URB	ECT$_{-1}$
ΔPEG	------	5.90*	1.14	0.65	-0.01*
ΔTRA	0.74	------	1.72	6.82*	-0.03
ΔFIB	8.47*	4.40**	------	1.05	-0.19
ΔURB	0.60	4.90**	1.17	------	-0.01

Specification 6: PEG, TRA, CIC, URB

Case 1

	ΔPEG	ΔGAT	ΔCIC	URB	ECT$_{-1}$
ΔPEG	------	5.32*	4.86**	16.1*	-0.65*
ΔTRA	1.88	------	4.22**	1.28	-0.02
ΔCIC	15.4*	2.86	------	0.78	-0.14
ΔURB	0.13	0.07	3.34	------	-0.04

Case 2

	ΔPEG	ΔPAT	ΔCIC	URB	ECT$_{-1}$
ΔPEG	------	3.47	5.33*	13.2*	-0.67*
ΔTRA	5.91*	------	0.44	5.24*	-0.03
ΔCIC	14.5*	2.78	------	0.34	-0.16
ΔURB	0.33	1.47	4.66**	------	-0.01

Case 3

	ΔPEG	ΔGRA	ΔCIC	URB	ECT$_{-1}$
ΔPEG	------	5.28*	3.84	11.8*	-0.64*
ΔTRA	0.13	------	1.97	0.11	-0.16
ΔCIC	17.1*	0.74	------	2.49	-0.18
ΔURB	0.52	4.85**	2.43	------	-0.001

Case 4

	ΔPEG	ΔPRA	ΔCIC	URB	ECT$_{-1}$
ΔPEG	------	0.55	3.24	12.5*	-0.67*
ΔTRA	4.34**	------	0.84	0.64	-0.03
ΔCIC	15.4*	1.69	------	1.77	-0.19
ΔURB	0.27	0.14	5.10*	------	-0.01

Case 5

	ΔPEG	ΔRAL	ΔCIC	URB	ECT$_{-1}$
ΔPEG	------	4.51**	2.02	17.2*	-0.83*
ΔTRA	2.92	------	1.16	1.09	-0.02
ΔCIC	6.29*	2.92	------	0.95	-0.11
ΔURB	0.14	0.31	4.70**	------	-0.01

Case 6

	ΔPEG	ΔCIT	ΔCIC	URB	ECT$_{-1}$
ΔPEG	------	5.12**	0.61	6.14*	-0.23*
ΔTRA	1.26	------	0.51	1.58	-0.07
ΔCIC	10.3*	5.04*	------	1.98	-0.21
ΔURB	0.32	3.83	4.20**	------	-0.02

Note 1: PEG is per capita economic growth, TRA is transport infrastructure, TEL is telephone land lines, MOB is mobile phones, INU is internet users, INS is internet servers, FIB is fixed broadband, CIT is composite index of ICT infrastructure, GAT is goods carried by air transport, PAT is passengers carried by air transport, GRA is goods carried by railways, PRA is passengers carried by railways, RAL is railways lines, CIT is composite index of transport infrastructure, URB is urbanization, and ECT$_{-}$ is lagged error-correction term.

Note 2: TRA indicates GAT, PAT, GRA, PRA, RAL, or CIT; * and ** indicate that parameter estimates are significant at the 5% and 10% levels, respectively.

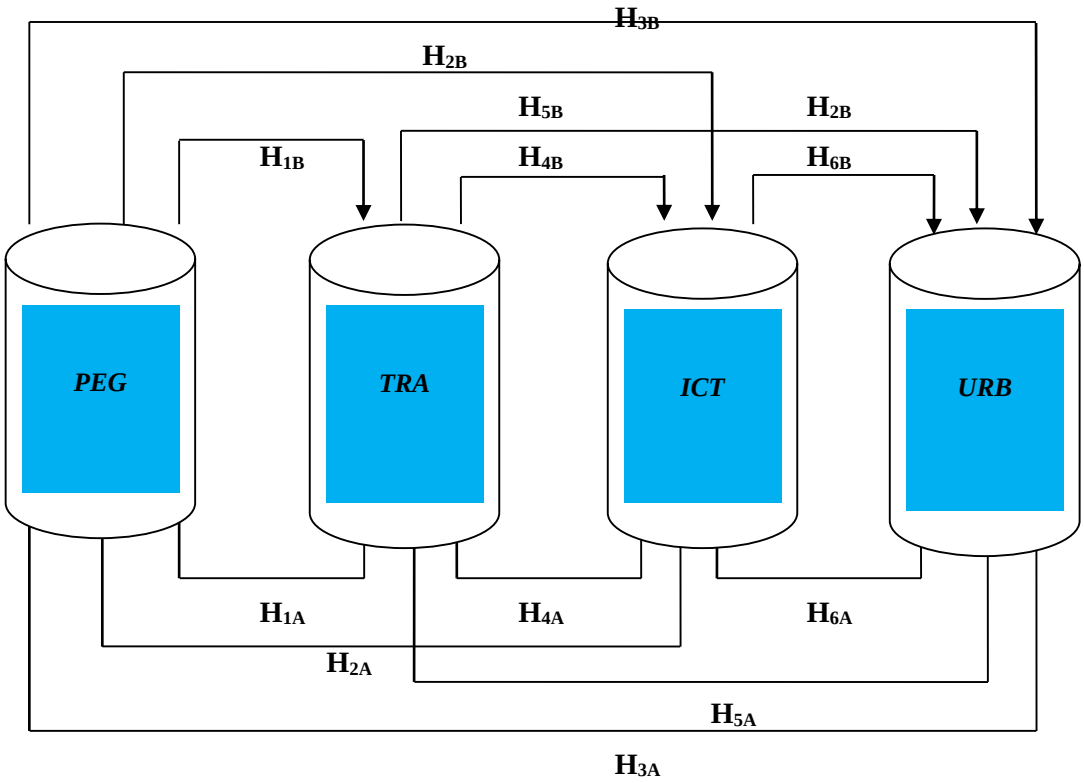
Table 2. Summary of Short-run Granger Causality Test

Specification 1	**Different Cases**					
TEL	1: GAT	2: PAT	3: GRA	4: PRA	5: RAL	6: CIT
PEG TRA	TRA => PEG	TRA <=> PEG	TRA => PEG	TRA => PEG	TRA <= PEG	TRA => PEG
PEG TEL	TEL<= PEG	TEL<= PEG	TEL <= PEG	TEL<= PEG	TEL<= PEG	TEL<= PEG
PEG URB	URB <=> PEG	URB <=> PEG	URB <=> PEG	URB <=> PEG	URB <=> PEG	URB <=> PEG
TRA TEL	TEL => TRA	TEL <#> TRA	TEL <#>TRA	TEL <#> TRA	TEL <#> TRA	TEL <#>TRA
TRA URB	URB => TRA	URB => TRA	URB <= TRA	URB => TRA	URB => TRA	URB <=> TRA
TEL URB	URB => TEL	URB =>TEL	URB =>TEL	URB =>TEL	URB <#>TEL	URB => TEL
Specification 2	**Different Cases**					
MOB	1: GAT	2: PAT	3: GRA	4: PRA	5: RAL	6: CIT
PEG TRA	TRA <= PEG	TRA <=> PEG	TRA => PEG	TRA <= PEG	TRA <=PEG	TRA => PEG
PEG MOB	MOB => PEG	MOB <=> PEG	MOB <=> PEG	MOB <=> PEG	MOB <=> PEG	MOB <=> PEG
PEG URB	URB <=> PEG	URB <=> PEG	URB => PEG	URB => PEG	URB => PEG	URB <#> PEG
TRA MOB	MOB <= TRA	MOB <= TRA	MOB <#> TRA	MOB <#> TRA	MOB <#>TRA	MOB => TRA
TRA URB	URB => TRA	URB => TRA	URB <#> TRA	URB <#> TRA	URB => TRA	URB => TRA
MOB URB	URB <= MOB	URB <=> MOB	URB <#> MOB	URB <#> MOB	URB =>MOB	URB <=> MOB
Specification 3	**Different Cases**					
INU	1: GAT	2: PAT	3: GRA	4: PRA	5: RAL	6: CIT
PEG TRA	TRA =>PEG	TRA => PEG	TRA => PEG	TRA <=PEG	TRA <= PEG	TRA => PEG
PEG INU	INU<=PEG	INU <=> PEG	INU <=PEG	INU <=PEG	INU <=> PEG	INU <= PEG
PEG URB	URB <=PEG	URB <= PEG	URB =>PEG	URB =>PEG	URB =>PEG	URB => PEG
TRA INU	INU =>TRA	INU <=> TRA	INU <= TRA	INU <=TRA	INU <=TRA	INU =>TRA
TRA URB	URB => TRA	URB <=> TRA	URB <=#>TRA	URB <#> TRA	URB <#> TRA	URB <=> TRA
INU URB	URB <=>INU	URB <= INU	URB <= INU	URB => INU	URB <= INU	URB <= INU
Specification 4	**Different Cases**					
INS	1: GAT	2: PAT	3: GRA	4: PRA	5: RAL	6: CIT
PEG TRA	TRA => PEG	TRA <= PEG	TRA => PEG	TRA <=> PEG	TRA <= PEG	TRA => PEG
PEG INS	INS <= PEG	INS <= PEG	INS <= PEG	INS <= PEG	INS <= PEG	INS <= PEG
PEG URB	URB => PEG	URB => PEG	URB => PEG	URB => PEG	URB => PEG	URB => PEG
TRA INS	INS => TRA	INS <#>TRA	INS <#>TRA	INS <#>TRA	INS <#>TRA	INS <#>TRA
TRA URB	URB <#> TRA	URB => TRA	URB <= TRA	URB <#> TRA	URB <#> TRA	URB <#> TRA
INS URB	URB => INS	URB => INS	URB =>INS	URB => INS	URB => INS	URB => INS
Specification 5	**Different Cases**					
FIB	1: GAT	2: PAT	3: GRA	4: PRA	5: RAL	6: CIT
PEG TRA	TRA => PEG	TRA => PEG	TRA => PEG	TRA <= PEG	TRA <= PEG	TRA => PEG
PEG FIB	FIB <=> PEG	FIB <=> PEG	FIB <=> PEG	FIB <= PEG	FIB <=> PEG	FIB <= PEG
PEG URB	URB => PEG	URB => PEG	URB => PEG	URB => PEG	URB => PEG	URB => PEG
TRA FIB	FIB <#> TRA	FIB <#> TRA	FIB => TRA	FIB <#> TRA	FIB <= TRA	FIB <= TRA

TRA URB	URB <#> TRA	URB => TRA	URB <#> TRA	URB <#> TRA	URB <#> TRA	URB <=> TRA
FIB URB	URB <#> FIB	URB => FIB	URB => FIB	URB <#> FIB	URB <=> FIB	URB <#> FIB
Specification 6	**Different Cases**					
CIC	1: GAT	2: PAT	3: GRA	4: PRA	5: RAL	6: CIT
PEG TRA	TRA => PEG	TRA <= PEG	TRA => PEG	TRA <= PEG	TRA => PEG	TRA => PEG
PEG CIC	CIC <=> PEG	CIC <=> PEG	CIC <= PEG	CIC <= PEG	CIC <= PEG	CIC <= PEG
PEG URB	URB = > PEG	URB => PEG	URB => PEG	URB => PEG	URB => PEG	URB => PEG
TRA CIC	CIC => TRA	CIC => TRA	CIC <#> TRA	CIC => TRA	CIC <#> TRA	CIC <= TRA
TRA URB	URB <#> TRA	URB => TRA	URB <= TRA	URB <#> TRA	URB <#> TRA	URB <#> TRA
CIC URB	URB <#>CIC	URB <= CIC	URB <#> CIC	URB <= CIC	URB <= CIC	URB <= CIC

Note 1: PEG is per capita economic growth, TRA is transport infrastructure, TEL is telephone land lines, MOB is mobile phones, INU is internet users, INS is internet servers, FIB is fixed broadband, CIT is composite index of ICT infrastructure, GAT is goods carried by air transport, PAT is passengers carried by air transport, GRA is goods carried by railways, PRA is passengers carried by railways, RAL is railways lines, CIT is composite index of transport infrastructure, URB is urbanization, and ECT$_{-1}$ is lagged error-correction term.

***Note 2*:** =>/<=, <=>, and <#> relate to unidirectional, bidirectional, and no Granger causality between these variables.



Note 1: *PEG* is the per capita economic growth rate; *TRA* is transportation; ICT is ICT infrastructure; and *URB* is urbanization.

Figure 1. Proposed Hypotheses