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Causal relationship between ICT R&D investment and economic growth in Korea

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ABSTRACT

This study examined the Granger-causality between R&D investment and economic growth for Korea's ICT industry. Bidirectional Granger-causality was observed between ICT R&D investment and economic growth, and this result implies that ICT R&D investment is driven by economic growth and vice versa. When ICT R&D investment was classified into public sector and private sector, the results showed the private ICT R&D investment had stronger relationship with economic growth compared to public the ICT R&D investment. It means the private ICT R&D investment has stronger attribute of leading economic growth and induced investment by economic growth than the Public ICT R&D investment. The results also reported bidirectional causality between public ICT R&D investment and private ICT R&D investment. The establishment of two-way Granger-causality between public sector and private sector indicates a virtuous cycle has taken hold.

1. Introduction

Information and communication technologies (ICTs) are key enablers of innovation throughout the economy. Inmost OECD economies, information industries account for the largest share of business expenditures on research and development, amounting to about 25% of total business expenditures on research and development and 0.2% to 0.4% of GDP. Especially, in Finland, Israel, Korea and the United States, information industries account for 40% to over 50% of BERD, and ICT BERD alone represents between about 0.6% to >1.8% of GDP, reflecting the high research intensity of these economies and the sector itself (OECD, 2015).

With the sector of ICT attracting vast R&D investments in various countries, many studies have been performed to determine the relationship between ICT investment and economic growth. Representative studies have been conducted by Madden and Savage (1998), Oliner and Sichel (2000), Jorgenson (2001, 2005), Colecchia and Schreyer (2002), Plepys (2002), Datta and Agarwal (2004), Jorgenson and Motohashi (2005), Jalava and Pohjola (2008), Koutroumpis (2009), Martínez et al. (2010), Vu (2011, 2013), and Sassi and Goaied (2013). Many of these studies demonstrate a strong positive correlation between ICT investment and economic growth.

However, as asserted by Blomstrom et al. (1996) and Madden and Savage (1998), a strong correlation between investment and economic growth does not necessarily imply the presence of a causal relationship; the correlation between the two variables can be either bi-directional or uni-directional. Phillips (1986) also claims that a causal relationship may be formed due to contingent regression despite the lack of correlation between the two variables. Since the establishment of a relationship dependent on correlation may invite inappropriate policies, further examination is needed on the causal relationship of the two variables.

The purpose of this study is to determine the causal relationship between R&D investment in the ICT industry and economic growth in Korea. According to the OECD (2015), OECD member countries invest about 20 to 25% of total industrial R&D investments in the ICT industry, and Korea recorded the highest investment at 56% of that. Given that the ICT industry accounts for a significant portion of Korea's R&D investment, it is essential to examine the causal relationship between ICT R&D investment and economic growth.

The characteristics of this study are as follows. First, it examines the causal relationship between R&D investment in the ICT industry and economic growth in Korea. Existing studies broadly define ICT investment as both capital investment and R&D investment due to difficulties involved in acquiring statistical data on R&D investment by industry. However, adopting this same approach to the situation in Korea would result in unreliable results since Korea's capital investment in ICT is 4 to 12 times greater than R&D investment. Second, this study analyzes the causal relationship between the two variables from multiple perspectives, and both public and private sectors are included when studying the general causal relationship between total R&D investment in ICT and economic growth. Next, ICT R&D investment is classified into public R&D investment and private R&D investment to assess the formation of a causal relation between each investment type and economic

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growth. Lastly, the causal relationship between ICT R&D investment and economic growth is reviewed based on the causal relationship between public R&D investment and private R&D investment.

This study is organized as follows. Section 2 introduces other studies covering the causal relationship between R&D investment in the ICT industry and economic growth. Section 3 examines the data and analytical model used in this study. Section 4 presents the results of analysis of the causal relationship between ICT R&D investment and economic growth. Section 5 provides a summary of the results and implications for related policies.

2. Literate review

Over the past several years, the role of telecommunications investment in economic development has been studied both using cross-section and modern advanced in time series econometrics of cointegration and causality (Wolde-Rufael, 2007). Many studies have been performed on the causal relationship between ICT investment and economic growth, from Cronin et al. (1991) to Ishida (2015). Table 1 lists representative studies in the field.

Studies focusing on the causal relationship between ICT investment and economic growth in a single country are as follows. Cronin et al. (1991), who examined the causal relationship between the two variables in the United States, found a feedback process in which telecommunications investment enhances economic activity and growth, while economic activity and growth stimulate demands for telecommunications infrastructure investment. However, Beil et al. (2005) stated that investment by telecommunications form is caused by, but does not cause, economic activity. Yoo and Kwak (2004), who analyzed the case of Korea, and Veeramacheneni et al. (2008), who examined the case of India, found bi-directional causality between IT investment and economic development. Dvorjnik and Sabolic (2007), who targeted countries in Eastern Europe, found that uni-directional causality runs from IT investment to economic development. In contrast, studies by Shiu and Lam (2008) on China and by Hossein and Yazdan (2012) on Iran found that uni-directional causality runs from economic growth to telecommunication development. Meanwhile, Ishida (2015), who dealt with the influence of Japan's ICT investment on economic growth and energy consumption, found that ICT investment could ceteris paribus contribute to a moderate reduction in energy consumption, but not to an increase in GDP.

Studies on the causal relationship between ICT investment and economic growth in multiple countries are as follows. Dutta (2001) examined the causal relationship between telecommunications infrastructure and economic activity in 15 developing countries and 15 industrialized countries. He found that the evidence for causality from levels of telecommunications infrastructure to economic activity is stronger than that for causality in the opposite direction. Veeramacheneni et al. (2007), whose study involved 10 countries in Latin America, found a bi-directional causal relationship between ICT and economic growth for seven countries, including Brazil. In addition, Pradhan et al. (2014) showed a bi-directional causal relationship between the development of telecommunications infrastructure and economic growth in both the G-20 developed group and the G-20 developing group.

3. Data and methodology

3.1. Data

3.1.1. Range of the ICT industry

The Korean Standard Industrial Classification (KSIC) does not classify the ICT industry as an independent industry. This study applied the KSIC model after classifying the ICT industry as an industry on its own, using the classification method developed by Hong et al. (2012). Details of the classification of ICT industry in this study are given in Table 2.

3.1.2. Variables

This study used annual time series data from the 26 year period between 1988 and 2013. Statistical data on value-added by industry, obtained from the Korean Statistical Information Service, was used as proxy variables of economic growth. The proxy variable of ICT R&D investment was statistical data on R&D investment by industry, provided by the National Science & Technology Information Service. Table 3 gives the data used for the empirical analysis in this study. The key variables of this study are value-added of the ICT industry (IGDP) and total R&D investment (TRDI). The TRDI of the ICT industry was divided into public R&D investment (GRDI) and private R&D investment (PRDI) to allow a multi-faceted analysis of the causal relationship between variables. All data was converted into real values through the 2010 GDP deflator provided by the Bank of Korea, and substituted into the model after taking natural logs.

3.2. Methodology

According to the Monte Carlo evidence reported by Guilkey and Salemi (1982) and Geweke et al. (1983), among the many techniques Granger-causality tests provide the most reliable results in the case of small samples. Thus, this study performed Granger-causality tests to analyze the causality between ICT R&D investment and economic growth. As proven by Stock and Watson (1989), non-stationary variables in time series data can lead to spurious regression, which calls for stable time series data. Since economic time series variables tend to be non-stationary, the stability of the time series data used in this study was assessed through unit root tests and the cointegration test.

3.2.1. Unit root test

The unit root originated from when a non-stationary time series is expressed as an autoregressive model, it takes the characteristic root of 1. If a certain variable has a unit root, that variable is said to follow a random walk, and can be converted to a stable variable using the difference method. Because the test equation cannot be predetermined for

Table 1
Literature review related causal relationship between IT investment and economic growth.

Research	Country	Period	Variables
Cronin et al. (1991)	U.S.A	1958–1988	GNP, telecom investment, total output
Dutta (2001)	30 countries	1970–1993	Economic activity level, telecom infrastructure level
Yoo and Kwak (2004)	Korea	1965–1998	GDP, IT investment
Beil et al. (2005)	U.S.A	1947–1996	FDP, telecom investment
Dvorjnik and sabolic (2007)	Eastern Europe	1991–2001	GDP, degree of telecom development
Veeramacheneni et al. (2007)	10 Latin American countries	1975–2003	GDP, telecom investment, foreign direct investment
Veeramacheneni et al. (2008)	India	1970–2005	economic activity level, telecom infrastructure level
Shiu and Lam (2008)	China and its region	1978–2004	GDP, teledensity, penetration rate
Hossein and Yazdan (2012)	Iran	1980–2010	GDP, ICT development
Pradhan et al. (2014)	G-20 countries	1991–2012	GDP, telecom infrastructure, macroeconomic variables
Ishida (2015)	Japan	1980–2010	GDP, ICT investment, energy consumption

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Table 2
The classification of the ICT industry in this study.
Source: Statistics Korea (1991, 2000, 2008).

Period	Industrial classification	Note
1988–1990	Manufacture of office, accounting and computing machinery	5th edition (1988.12)
	Manufacture of radio, television and communication equipment and apparatus	
	Manufacture of electronic valves and tubes and other electronic components	
1991–1998	Manufacture of office, accounting and computing machinery	6th edition (1991.9)
	Manufacture of radio, television and communication equipment and apparatus	7th edition (1998.2)
1999–2013	Manufacture of semiconductor	8th edition (2000.1)
	Manufacture of electronic components	9th edition (2008.2)
	Manufacture of computers and peripheral equipment	
	Manufacture of magnetic and optical medium	
	Manufacture of telecommunication and broadcasting apparatuses	
	Manufacture of electronic video and audio equipment	

a given time series, unit root tests are required. Key techniques of unit root tests are the Dickey-Fuller (DF) test, the Augmented Dickey-Fuller (ADF) test, and the Phillips-Perron (PP) test.

The DF test, first proposed by Dickey-Fuller, is rather limited in that it assumes that the correction term is free of autocorrelation and heteroscedasticity. The ADF test is most widely used as it accounts for possible serial correlation in the correction term by adding lagged dependent variables, but assumes that the correction term is free of heteroscedasticity. The PP test makes a non-parametric correction for serial correlation while taking into consideration both autocorrelation and heteroscedasticity. This test is known to be robust to various types of autocorrelation and time-dependent heteroscedasticity. However, Schwert (1987) recommended cross-testing with ADF because of the tendency of the PP test to reject the null hypothesis that the time series is non-stationary, and Davidson and Mackinnon (2004) claimed that the ADF test is superior to the PP test for small samples.

If lags are increased during unit root tests, the estimation model has less bias but increased variance. If lags are limited to a short run, the unit root tests will have increased bias. To resolve these issues, some standards must be established to select the optimal length of lags. In general, unit root tests adhere to the Akaike's Information Criterion (AIC) or Schwartz Criterion (SC). Considering that only 26 data sets were used in this study, ADF tests were performed to assess the unit root of each variable, and the optimal lag length was selected based on the Schwartz Criterion.

Table 3
Statistics of the variables in this study.

Year	IGDP	TRDI	GRDI	PRDI
1988	14,391,661	1,134,978	23,777	1,111,201
1989	15,367,396	1,513,801	39,349	1,474,452
1990	17,892,985	1,596,336	27,686	1,568,649
1991	17,690,401	1,904,489	111,937	1,792,552
1992	16,983,863	2,010,445	52,759	1,957,686
1993	21,047,220	2,467,317	57,847	2,409,470
1994	27,111,533	2,813,639	43,343	2,770,296
1995	39,015,465	3,406,261	109,935	3,296,325
1996	39,854,938	3,898,696	180,418	3,718,278
1997	36,839,128	4,315,619	169,072	4,146,548
1998	38,008,232	3,738,943	149,224	3,589,718
1999	49,829,429	5,034,118	262,200	4,771,918
2000	57,179,127	5,804,084	221,696	5,582,388
2001	49,460,921	6,657,020	256,123	6,400,897
2002	55,913,901	7,297,949	203,507	7,094,443
2003	58,621,765	7,851,360	210,619	7,640,742
2004	75,360,860	9,318,957	136,944	9,182,013
2005	74,429,078	10,186,308	144,099	10,042,209
2006	77,526,934	11,710,435	186,214	11,524,221
2007	78,488,167	11,924,849	262,165	11,662,684
2008	81,756,957	12,873,335	242,951	12,630,385
2009	92,745,464	13,230,253	332,126	12,898,127
2010	108,684,981	15,824,981	331,217	15,493,764
2011	113,741,691	17,683,829	316,714	17,367,115
2012	112,880,907	20,246,603	372,043	19,874,560
2013	112,878,766	22,558,501	302,657	22,255,844

3.2.2. Cointegration test

If a stable linear combination exists among non-stationary time series data having unit roots, this linear combination is known as cointegration. Important information on long-term relationships among time series will be lost if regression analysis is performed using lagged variables, and so cointegration tests are essential when analyzing economic variables. In other words, spurious regression can be avoided by performing cointegration tests.

Cointegration tests can be classified into the regression residual-based test and equation-based test. The residual-based cointegration test determines the stability of the regression residual through unit root tests, and involves the Engle-Granger two-step (EG-ADF) procedure and the Phillips-Ouliaris (PO) test. The former is an expansion of ADF unit root tests while the latter is based on PP unit root tests. The equation-based test is applied in the presence of two or more cointegration relationships, and is best represented by the Johansen test. The Johansen test, regarded as the most superior cointegration test, enables various hypothesis testing in addition to estimating the cointegration parameter. In a comparison of five commonly used cointegration tests by Gonzalo (1994), the maximum likelihood estimation method proposed by Johansen (1988) and Johansen and Juselius (1988) was found to be the most effective. Thus, this study employed the Johansen method in analyzing the cointegration of time series variables for ICT R&D investment and economic growth.

Similar to unit root tests, optimal lags must be selected for cointegration tests to reduce bias and ensure accurate results. Based on the Schwarz Criterion, optimal lags were selected to minimize SC statistics.

3.2.3. Vector error correction model

When cointegration exists between two variables, causality analysis must be performed using an error correction model with a test equation containing the error correction term. If the Granger-causality analysis is conducted despite the presence of cointegration, it will fail to accurately capture the causality relationship. The error correction model is capable of simultaneously examining short and long run causality because it not only covers the effects of differences in the lagged terms of independent variables on dependent variables, but also the effects of changes in the error correction term on dependent variables.

$$\Delta Y_t = \alpha_1 + \sum_{i=1}^{L_{11}} \beta_{11i} \Delta Y_{t-i} + \sum_{j=1}^{L_{12}} \beta_{12j} \Delta X_{t-j} + \gamma_1 \hat{\varepsilon}_{t-1} + \mu_{1t} \quad (1)$$

$$\Delta X_t = \alpha_2 + \sum_{i=1}^{L_{21}} \beta_{21i} \Delta X_{t-i} + \sum_{j=1}^{L_{22}} \beta_{22j} \Delta Y_{t-j} + \gamma_2 \hat{\varepsilon}_{t-1} + \mu_{2t} \quad (2)$$

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The causality test model, with the error correction term in the test equation, can be expressed as shown in Eqs. (1) and (2). This is referred to as the vector error correction model (VECM). Here, α, β and γ are coefficients of the polynomial, where L is the optimal lag, $\hat{\varepsilon}_{t-1}$ is the correction term, and μ_t is the disturbance term.

Eq. (1) expresses the causality test model from X to Y. If the null hypothesis ($H_0 : \beta_{12j} = 0$) is rejected in Eq. (1), short run Granger-causality is established from X to Y. The coefficient (γ_1) of the error correction term shows the speed of adjustment towards equilibrium. The coefficient (γ_1) of the error correction term shows the speed of adjustment towards equilibrium. As such, if the null hypothesis ($H_0 : \gamma_1 = 0$) is rejected, long run Granger-causality is established from X to Y. Eq. (2) represents the causality test model from Y to X. Rejection of the null hypothesis $H_0 : \beta_{22j} = 0$ and $H_0 : \gamma_2 = 0$ reflects short run Granger-causality and long run Granger-causality from Y to X, respectively.

To test the causality using the error correction model, the lag length of independent variables must first be determined. Since lag length can have a significant influence over test results, it should be carefully selected to ensure accuracy. Generally, the optimal lag length is chosen while adhering to either the Akaike Information Criterion or Schwarz Criterion. This study determined the optimal lag length of the error correction model under the Schwarz Criterion.

4. Results

4.1. Unit root test

In selecting a model for unit root tests, this study applied a model that accounts for both intercepts and trends. The former was included because it is generally accounted for in unit root tests, and the latter to allow more detailed examination of the time series data. The optimal lag length was one that minimized the SC value in accordance with the Schwarz Criterion. Table 4 shows the results of ADF unit root tests for the ICT R&D investment time series data and ICT value added time series data. IGDP, TRDI, GRDI, and PRDI each represent the value added of the ICT industry, total R&D investment of the ICT industry, public R&D investment in the ICT industry, and private R&D investment in the ICT industry. All variables failed to reach critical values at 5% significance level of the *t*-test, and the null hypothesis that unit roots do not exist could not be rejected. The first difference variables of IGDP, TRDI, GRDI, and PRDI surpassed critical values at 5% significance level, thus rejecting the null hypothesis that the time series data has no unit roots. All variables introduced in the model fell under non-stationary time series data, but the first difference variables were found to be stable time series data with no unit roots.

4.2. Cointegration test

In selecting a model for the cointegration test, a linear deterministic trend was assumed for the time series. The cointegration equation included intercepts but not trends. Among the likelihood ratio tests proposed by Johansen, the trace statistic was used to test for cointegration. Similar to unit root tests, the lag length that minimizes SC was selected as the optimal lag. Table 5 shows the results of the cointegration test between ICT R&D investment and ICT value added. The null hypothesis ($H_0^1 : R = 0$) that cointegration does not exist at 5% was rejected by IGDP and TRDI, IGDP and GRDI, IGDP and GRDI, and GRDI and PRDI, indicating that cointegration exists among variables. The null hypothesis ($H_0^2 : R \leq 1$) that a maximum of one cointegration exists could not be rejected, which means that one cointegration exists.

Table 5
Results of the Johansen cointegration test.

	Null hypothesis	Trace statistic	Critical value	*p*-Value	Optimal time lag
IGDP	$H_0^1 : R = 0$	42.0265	15.4947	0.0000	6
TRDI	$H_0^2 : R \leq 1$	2.3408	3.8415	0.1260	
IGDP	$H_0^1 : R = 0$	18.2406	15.4947	0.0188	5
GRDI	$H_0^2 : R \leq 1$	3.3593	3.8415	0.0668	
IGDP	$H_0^1 : R = 0$	42.0082	15.4947	0.0000	6
PRDI	$H_0^2 : R \leq 1$	2.7701	3.8415	0.0960	
GRDI	$H_0^1 : R = 0$	45.1103	15.4947	0.0000	6
PRDI	$H_0^2 : R \leq 1$	0.1853	3.8415	0.6669	

Note: Critical values are values at 5% significance level as proposed by MacKinnon et al. (1999).

4.3. Causality analysis using a vector error correction model

Similar to the cointegration model, the error correction model for Granger-causality analysis included intercepts but not trends. In selecting the optimal lag, a lag length was selected in accordance with SC as shown in Table 6. In this study, considering the small sample of the time series used in the error correction model, statistical significance was tested at a significance level of 10%.

First, the results of the Granger-causality test on total ICT R&D investment and ICT value added are as follows. The results showed short run causality running from TRDI to IGDP with an *F*-statistic and *p*-value of 3.6063 and 0.0528, respectively, as well as long run causality with an error correction coefficient and *p*-value of −0.9013 and 0.0050, respectively. In addition, the results reported short run causality running from IGDP to TRDI with an *F*-statistic and *p*-value of 4.2429 and 0.0351, respectively. But long run causality in the same direction was found to be insignificant due to the *p*-value of the error correction coefficient was 0.7385.

Second, the results of the Granger-causality test on public ICT R&D investment and ICT value added are as follows. The results showed short run causality running from GRDI to IGDP with an *F*-statistic and *p*-value of 4.2646 and 0.0252, respectively, but not long run causality due to the positive sign despite the *p*-value of the error correction coefficient being 0.0005. However, short run causality not established running from IGDP to GRDI with *p*-value of 0.9137, and long run causality was not reported in the same direction with the *p*-value of the error correction coefficient being 0.2142.

Third, the results of the Granger-causality test on private ICT R&D investment and ICT value added are as follows. The results showed short run causality running from PRDI to IGDP with an *F*-statistic and *p*-value of 3.4019 and 0.0568, respectively, as well as long run causality

Table 4
Results of the ADF unit root test.

	Level			1st difference		
	t-statistic	Critical value	*p*-value	*t*-statistic	Critical value	*p*-Value
IGDP	−1.1118	−3.6329	0.9038	−5.4681	−3.6329	0.0012
TRDI	−3.5497	−3.6032	0.0555	−7.3024	−3.6121	0.0000
GRDI	−3.2564	−3.6032	0.0967	−7.7463	−3.6122	0.0000
PRDI	−3.4495	−3.6032	0.0674	−3.7959	−3.6122	0.0001

Note: Critical values are values at 5% significance level as proposed by MacKinnon (1996).

Table 6
Optimal time lag of the vector error correction models.

	1	2	3	4	5
IGDP TRDI	−3.2585	−3.0895	−2.7248	−3.0025	−3.4684
IGDP GRDI	−0.1851	0.2341	0.1889	−0.2653	0.1112
IGDP PRDI	−3.1753	−2.8413	−2.5707	−3.0623	−3.4749
GRDI PRDI	−0.4751	−0.0236	−0.2862	−0.5271	−1.1362

Table 7
Results of the residual diagnostics.

	Jargue-Bera statistics	Breusch-Godfrey LM statistics	Breusch-Pagan-Godfrey statistics
TRDI ≠ > IGDP	1.5098	0.8936	0.5511
	(0.4701)	(0.5757)	(0.8261)
IGDP ≠ > TRDI	2.2329	0.2146	0.2081
	(0.3274)	(0.9346)	(0.9913)
GRDI ≠ > IGDP	0.4102	1.6948	1.8542
	(0.8146)	(0.2544)	(0.1723)
PRDI ≠ > IGDP	1.3656	1.6375	0.5672
	(0.5052)	(0.3633)	(0.8148)
IGDP ≠ > PRDI	1.4055	0.2909	0.2404
	(0.4952)	(0.8914)	(0.9849)
GRDI ≠ > PRDI	1.9583	1.3294	0.5401
	(0.3756)	(0.4336)	(0.8337)
PRDI ≠ > GRDI	2.0499	0.7830	0.6377
	(0.3588)	(0.6227)	(0.7646)

Note1: The '≠>' symbol in null hypothesis indicates that Granger-causality is not observed from the left variable to the right variable.
Note2: The number in parenthesis refers to the *p*-value statistic.

with an error correction coefficient and *p*-value of −0.8556 and 0.0067, respectively. Further, the results reported short run causality running from IGDP to PRDI with an *F*-statistic and *p*-value of 4.1168 and 0.0379, respectively. But, long run causality in the same direction was found to be insignificant since the *p*-value of the error correction coefficient was 0.4392.

Fourth, the results of the Granger-causality test on public ICT R&D investment and private ICT R&D investment are as follows. The results reported short run causality running from GRDI to PRDI with an *F*-statistic and *p*-value 2.8654 and 0.0898, respectively, but not long run causality since the *p*-value of the error correction coefficient was 0.3672. In contrast, the results showed short run causality running from PRDI to GRDI with an *F*-statistic and *p*-value of 4.2485 and 0.0349, respectively, as well as long run causality with an error correction coefficient and *p*-value of −0.8502 and 0.0011, respectively.

Table 7 shows the normal distribution for the residual of the error correction model, serial correlation and heteroscedasticity, tested respectively using Jarque-Bera test, Breusch-Godfrey LM test, and Breusch-Pagan–Godfrey test. All residuals of models were found to follow a normal distribution. Problems were not detected for serial correlation and heteroscedasticity, thereby attesting to the reliability of estimations provided by the error correction model.

Table 8 provides a comprehensive overview of Granger-causality between Korea's ICT R&D investment and economic growth. Between total ICT R&D investment and economic growth, short run causality and long run causality from the former to the latter and short run causality from the latter to the former were observed. When total ICT R&D investment was classified into public sector and private sector, the results showed only unidirectional short run causality was found from public ICT R&D investment to economic growth between the two variables. But, between the private ICT R&D investment and economic growth, the results reported short run causality and long run causality from the former to the latter as well as short run causality from the latter to the former. Between public and private R&D investment, short run causality from the former to the latter was found with short run and long run causality from the latter to the former.

Table 8
Summarized results of the causal relationship between ICT R&D investment and economic growth in Korea.

Variable	Short-run causality	Long-run causality	Variable
TRDI	→	→	IGDP
	←		
GRDI	→		IGDP
PRDI	→	→	IGDP
	←		
GRDI	→	←	PRDI
	←		

Note: '→' indicates Granger-causality from left to right, while '←' indicates Granger-causality from right to left.

5. Conclusion

This study examined causal relationships between Korea's R&D investment in the ICT industry and economic growth. Before causality tests, unit root tests were performed to assess the stability of the time series data. All introduced variables were non-stationary but their first difference variables were found to be stable. Cointegration was employed to determine whether a stable linear combination exists between the two variables, and one cointegration relationship was observed in all models. Since a cointegration relationship exists between the two time series, granger-causality was tested using the vector error correction model.

According to the results, between the total ICT R&D investment and the ICT value added established bidirectional causality. When total ICT R&D investment was classified into public sector and private sector, the private ICT R&D investment had stronger relationship with economic growth compared to the public ICT R&D investment. The results also reported bidirectional causality between public ICT R&D investment and private ICT R&D investment, and this relationship was revealed to be more greatly influenced by the latter.

The implications derived from this study are as follows. First, the establishment of bidirectional causality between total ICT R&D investment and economic growth implies that ICT R&D investment is driven by economic growth and vice versa. Based on the short run causality from economic growth to total ICT R&D investment and the short and long run causality from total ICT R&D investment to economic growth, we can presume that Korea's economic growth was driven by R&D in ICT over the long term.

Second, short run and long run causality from private R&D investment to economic growth, and short run causality from public R&D investment to economic growth indicate that the private R&D investment has stronger attribute of leading economic growth than the public R&D investment. In addition, the short run causality from economic growth to private R&D investment, and the lack of any significant causality from economic growth to public R&D investment imply that the private R&D investment has stronger attribute of induced investment by economic growth than the public R&D investment.

Third, the establishment of bidirectional causality between public ICT R&D investment and the private ICT R&D investment points to the presence of a virtuous cycle on both sides. An increase in public ICT R&D investment will not only lead to greater private investment, but also has the potential to create secondary added value. An increase in private R&D investment will have a positive impact on the growth of the public sector and contribute to national wealth, which can in turn allow higher R&D investment by the government.

This study has several limitations due to the limited sample. First, less stringent criteria was applied in causality tests because there were data for 26 years from 1988 to 2013. In future work, causality tests should be conducted on more data and under stricter conditions. Second, while the analysis period contained structural changes to the Korean economy, they could not be fully accounted for in the causality test because of the limited time series data. A consideration of structural changes will allow dynamic causality analysis, and more data should be acquired for a more in-depth examination of periods involving significant changes to the nation's economy.

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Appendix

Results of the Granger-causality analysis between IGDP and TRDI using a VECM.

Null hypothesis	Statistics	Short run causality	Long run causality
TRDI ≠ > IGDP	*F*-statistic	3.6063	–
	ECT coefficient	–	−0.9013
	(*t*-statistic)		(−3.8389)
	p-value	0.0528	0.0050
IGDP ≠ > TRDI	*F*-statistic	4.2429	–
	ECT coefficient	–	−0.0511
	(*t*-statistic)		(−0.3458)
	p-value	0.0351	0.7385

Note1: The '≠>' symbol in null hypothesis indicates that Granger-causality is not observed from the left variable to the right variable.
Note2: Considering the limited sample size in the time series, statistical significance was tested at 10% significance level.

Results of the Granger-causality analysis between IGDP and GRDI using a VECM.

Null hypothesis	Statistics	Short run causality	Long run causality
GRDI ≠ > IGDP	*F*-statistic	4.2646	–
	ECT coefficient	–	0.0456
	(*t*-statistic)		(4.8045)
	p-value	0.0252	0.0005
IGDP ≠ > GRDI	*F*-statistic	0.2335	–
	ECT coefficient	–	−0.2418
	(*t*-statistic)		(−1.3182)
	p-value	0.9137	0.2142

Note1: The '≠>' symbol in null hypothesis indicates that Granger-causality is not observed from the left variable to the right variable.
Note2: Considering the limited sample size in the time series, statistical significance was tested at 10% significance level.

Results of the Granger-causality analysis between IGDP and PRDI using a VECM.

Null hypothesis	Statistics	Short run causality	Long run causality
PRDI ≠ > IGDP	*F*-statistic	3.4019	–
	ECT coefficient	–	−0.8556
	(*t*-statistic)		(−3.6248)
	p-value	0.0568	0.0067
IGDP ≠ > PRDI	*F*-statistic	4.1168	–
	ECT coefficient	–	−0.1225
	(*t*-statistic)		(−0.8141)
	p-value	0.0379	0.4392

Note1: The '≠>' symbol in null hypothesis indicates that Granger-causality is not observed from the left variable to the right variable.
Note2: Considering the limited sample size in the time series, statistical significance was tested at 10% significance level.

Results of the Granger-causality analysis between GRDI and PRDI using a VECM.

Null hypothesis	Statistics	Short run causality	Long run causality
GRDI ≠ > PRDI	*F*-statistic	2.8654	–
	ECT coefficient	–	−0.0105
	(*t*-statistic)		(−0.9558)
	p-value	0.0898	0.3672
PRDI ≠ > GRDI	*F*-statistic	4.2485	–
	ECT coefficient	–	−0.8502
	(*t*-statistic)		(−4.9443)
	p-value	0.0349	0.0011

Note1: The '≠>' symbol in null hypothesis indicates that Granger-causality is not observed from the left variable to the right variable.
Note2: Considering the limited sample size in the time series, statistical significance was tested at 10% significance level.

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