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Electricity consumption and economic growth: evidence from Korea

Seung-Hoon Yoo*

School of Business and Economics, Hoseo University, 268 Anseo-Dong, Cheonan, Chungnam 330-713, Republic of Korea

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Abstract

This paper investigates the short- and long-run causality issues between electricity consumption and economic growth in Korea by using the co-integration and error-correction models. It employs annual data covering the period 1970–2002. The overall results show that there exists bi-directional causality between electricity consumption and economic growth. This means that an increase in electricity consumption directly affects economic growth and that economic growth also stimulates further electricity consumption.

Keywords: Electricity consumption; Economic growth; Causality; Unit root; Co-integration; Error correction model

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1. Introduction

In the past two decades, numerous studies have been conducted to examine the relationship between electricity consumption and economic growth. The overall findings show that there is a strong relationship between electricity consumption and economic growth. For example, Ferguson et al. (2000) has studied the issue in over 100 countries, and found that as a whole there is a strong correlation between electricity consumption and economic growth.

However, the fact that there exists a strong relationship between electricity consumption and economic growth does not necessarily imply a ‘‘causal’’ relationship. The relationship may very well run from electricity consumption to economic growth, and/or from economic growth to electricity consumption. These causality issues, therefore, suggest the need to carry out further investigations. A major question concerning this issue is which variable should take precedence over the other—is electricity consumption a stimulus for economic growth or does economic growth lead to electricity consumption?

Evidence on either direction shall have a significant bearing upon policy. If, for example, there is uni-directional causality running from electricity consumption to economic growth, reducing electricity consumption could lead to a fall in economic growth. On the other hand, if a uni-directional causality runs from economic growth to electricity consumption, it could imply that the policies for reducing electricity consumption may be implemented with little or no adverse effects on economic growth. And lastly, no causality in either direction would indicate that policies for increasing electricity consumption do not affect economic growth.

In a summary of the literature on the causal relationship between energy consumption including electricity consumption and economic growth, there are a number of evidences to support bi-directional or uni-directional causality between energy consumption and economic growth.[1] More specifically for electricity consumption, Yang (2000) found bi-directional causality between electricity consumption and economic growth in Taiwan, and Ghosh (2002) revealed that there exits uni-directional causality running from economic growth to electricity consumption in India without any feedback effect. More recently, Shiu and Lam (2004) showed that there is uni-directional causality running from electricity consumption to economic growth in China but not vice versa.

Public policy makers in Korea have shown a great deal of interest in the role that electricity consumption plays in economic growth. The electricity infrastructure of Korea is becoming an increasingly important component of the economy (Han et al., 2004). In particular, greater use of information and communications technologies (ICTs) marks a worldwide transition

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*Corresponding author. Tel.: +82-41-560-8344; fax: +82-41-563-0135.

E-mail address: shyoo@office.hoseo.ac.kr (S.-H. Yoo).

[1] A good overview of the literature is found in Table 1 given in Shiu and Lam (2004).

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towards a digital society that may profoundly affect electricity supply, demand, and delivery (Baer et al., 2002). In addition, as commonly known, electricity enhances the productivity of capital, labor, and other factors of production. To proactively cope with increasing electricity demand accompanying rapid economic growth, Korea should endeavor to uncover the causal relationship between electricity consumption and economic growth and to make appropriate electricity policy. This task has become one of the most important ones for Korea in the present and in the near future.

The purpose of this paper is, therefore, to investigate causality between electricity consumption and economic growth, and to obtain policy implications from our results. To this end, the author attempts to provide more careful consideration of the causality issues by applying modern rigorous techniques of Granger-causality to the Korean data. The methods adopted here are in the following fashion. First, stationarity and co-integration are tested; second, error-correction models are estimated to test for the Granger-causality; finally, the *F*- and *t*-tests are performed to gauge the joint significance levels of causality between the two variables. Through the analysis, instead of arbitrarily choosing a lag length, Akaike's information criterion described in Pantula et al. (1994) is employed to select the optimum lag.

The remainder of the paper is organized as follows. Section 2 presents an overview of the proposed methodology. Section 3 explains the data employed and reports the empirical findings. A summary, some policy implications and conclusions of the study are made in Section 4.

2. Methodology

2.1. Granger-causality and stationarity

The first attempt at testing for the direction of causality was proposed by Granger (1969). The Granger-causality test is a convenient and very general approach for detecting any presence of a causal relationship between two variables. The test is quite simple and straightforward. A time series (X) is said to Granger-cause another time series (Y) if the prediction error of current Y declines by using past values of X in addition to past values of Y. The Granger-causality test method is selected to be used in this study over other alternative techniques because of the favorable Monte Carlo evidence reported by Guilkey and Salemi (1982) and Geweke et al. (1983), particularly for small samples in empirical works.

In order to conduct to the Granger-causality test, a series of variables is required to be stationary. It has been shown that using non-stationary data in causality tests can yield spurious causality results (Granger and Newbold, 1974; Stock and Watson, 1989). Therefore, following Engle and Granger (1987), the author first tests the unit roots of X and Y to confirm the stationarity of each variable. This is done by using the Phillips–Perron (PP) (Phillips and Perron, 1988) test over alternative tests, in that the PP test is known to be robust for a variety of serial correlations and time-dependent heteroscedasticities. If any variable is found to be non-stationary, we must take the first difference and then apply the causality test with differenced data.

2.2. Co-integration

The concept of co-integration can be defined as a systematic co-movement among two or more economic variables over the long run. According to Engle and Granger (1987), if X and Y are both non-stationary, one would expect that a linear combination of X and Y would be a random walk. However, the two variables may have the property that a particular combination of them $Z = X - bY$ is stationary. Thus, if such a property holds true, then we say that X and Y are co-integrated.

If X and Y each are non-stationary and co-integrated, then any standard Granger-causal inferences will be invalid and a more comprehensive test of causality based on an error-correction model (ECM), should be adopted (Engle and Granger, 1987). However, if X and Y are both non-stationary and the linear combination of the series of two variables is non-stationary, then standard Granger-causality test should be adopted (Toda and Phillips, 1993; Yoo and Kwak, 2004). Therefore, it is necessary to test for the co-integration property of the series of electricity consumption and economic growth before performing the Granger-causality test. When both series are integrated of the same order, we can proceed to test for the presence of co-integration. The Johansen co-integration test procedure (Johansen and Juselius, 1990) is used for this purpose.

2.3. Error-correction model

In the error-correction modeling procedure, X Granger-causes Y, if either the estimated coefficients on lagged values of X or the estimated coefficient on lagged value of error term from co-integrated regression is statistically significant. Similarly, Y Granger-causes X, if either the estimated coefficients on lagged values of Y or the estimated coefficient on lagged value of error term from co-integrated regression is statistically significant. This procedure specifically allows for a causal linkage between two or more variables stemming from an equilibrium relationship, thus characterizing the long-run equilibrium alignment that persists beyond the short-run adjustment.

If two variables are non-stationary, but they become stationary after the first differencing, and co-integrated, the ECMs for the Granger-causality test can be specified accordingly as follows:

$$\Delta Y_t = \beta_{10} + \sum_{i=1}^{L_{11}} \beta_{11i}\Delta Y_{t-i} + \sum_{j=1}^{L_{12}} \beta_{12j}\Delta X_{t-j} + \beta_{13}\varepsilon_{t-1} + u_{1t}, \quad (1)$$

$$\Delta X_t = \beta_{20} + \sum_{i=1}^{L_{21}} \beta_{21i}\Delta Y_{t-i} + \sum_{j=1}^{L_{22}} \beta_{22j}\Delta X_{t-j} + \beta_{23}\varepsilon_{t-1} + u_{2t}, \quad (2)$$

where X_t and Y_t represent natural logarithms of electricity consumption and real GDP, respectively, Δ is the difference operator, Ls are the numbers of lags, βs are parameters to be estimated, u_ts are the serially uncorrelated error terms, and ε_{t-1} is the error correction term (ECT), which is derived from the long-run co-integration relationship, $Y_t = \eta_0 + \eta_1 X_t + \varepsilon_t$ where ηs are parameters to be estimated and ε_t is error term.

In each equation, the change in the dependent variable is caused not only by their lags, but also by the previous period's disequilibrium in level, ε_{t-1}. Given such a specification, the presence of short- and long-run causality can be tested. Let us consider Eq. (1). If the estimated coefficients on lagged values of electricity consumption (β_{12}s) are statistically significant, then the implication is that electricity consumption Granger-causes real GDP in the short run. This test can be conducted by a joint F-test. On the other hand, long-run causality can be found by testing the significance of the estimated coefficient of ECT (β_{13}) by a t-test. Finally, the strong Granger-causality can be exposed through a joint test of the statistical significance of β_{12}s and β_{13} by a joint F-test. Similar reasoning is possible for examining whether real GDP Granger-causes electricity consumption in Eq. (2).

3. Empirical results

3.1. Data

In order to investigate whether there is a causal relationship between electricity consumption and economic growth, data covering the period 1970–2002 are used. The choice of the starting period was constrained by the availability of data on electricity consumption. Electricity consumption is expressed in terms of gigawatt hours (GWh). The nominal GDP series in Korean currency units (won) are transformed into real GDP in constant 1995 prices using GDP deflators.[2] The variables used in the models are: *LEC*, natural logarithm of electricity consumption; and *LGDP*, natural logarithm of real GDP. The data on the two variables were obtained from the Korean Ministry of Commerce, Industry and Energy, and the Bank of Korea, respectively. Fig. 1 describes the two times series, electricity consumption and real GDP over the period 1970–2002.

3.2. Results of unit roots and co-integration tests

When testing for unit roots and co-integration the author has chosen to use a probability value of 0.10 in this study, which is an appropriate level of significance to be used with small sample sizes such as that used here. The results of the unit root tests for the series of *LEC* and *LGDP* variables are shown in Table 1. The PP test provides the formal test for unit roots in this study. The p-values of PP values calculated for the two series are larger than 0.10. This indicates that the series of all the variables are non-stationary at 10% level of significance and thus any causal inferences from the two series in levels are invalid. However, non-stationarity can be rejected for first differences of these series at 10% level of significance. Hence, the Granger-causality models are estimated with first-differenced data.

As indicated, the basic idea behind co-integration is to test whether a linear combination of two individually non-stationary time series is itself stationary. Given that

Table 1
Results of Phillips–Perron (PP) unit root tests

	Levels		First differences	
Variables	PP values	p-values	PP values	p-values
LEC	−3.42[2]	0.918	−25.73[2][a]	0.022
LGDP	−5.00[2]	0.821	−27.86[2][a]	0.014

Note: The numbers inside the brackets are the optimum lag lengths determined using Akaike's information criterion described in Pantula et al. (1994). The p-values are calculated under the null hypothesis of nonstationarity.

[a] Represents the rejection of the null hypothesis at 5% level of significance.

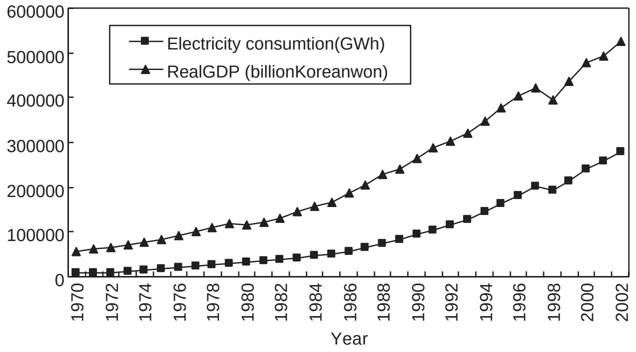

Fig. 1. Electricity consumption and real GDP in Korea.

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[2] The use of GDP, rather than gross national product, may be more appropriate in the analysis of the causal relationship, because the country's total electricity consumption depends upon goods and services produced within the country, not outside the country.

Table 2
Results of Johansen co-integration tests

Null hypotheses	Likelihood ratio test statistic	p-values
The number of co-integrating equation is zero ($R=0$).	17.775[a]	0.057
The number of co-integrating equation is at most one ($R\leqslant 1$).	3.355[a]	0.063

Note: The optimal lag length is chosen as eight by using Akaike's information criterion described in Pantula et al. (1994). The p-values are calculated under the corresponding null hypothesis. R denotes the number of co-integrating equation.

[a] Indicates the rejection of the null hypothesis at 10% level of significance.

integration of two series is of the same order, it is necessary to test whether the two series are co-integrated over the sample period. The results of the Johansen co-integration test for the series *LEC* and *LGDP* are reported in Table 2.

The likelihood ratio tests show that the null hypothesis of absence of co-integrating relation ($R=0$) can be rejected at 10% level of significance, and that the null hypothesis of existence of at most one co-integrating relation ($R\leqslant 1$) also can be rejected at 10% level of significance. This implies that there are two co-integrating equations at 10% level of significance. However, only one co-integrating equation of the two is consistent with Fig. 1 and the theory in literature, that is, there is positive relationship between electricity consumption and real GDP. Evidence in this study indicates that the integrated variables have inherent co-movement tendency over the long run. Thus, the author concludes that electricity consumption and real GDP are co-integrated. That is, there is a long-run relationship between electricity consumption and real GDP for Korea.

3.3. *Results of error-correction model and Granger-causality tests*

As stated above, if the series of two variables are non-stationary and the linear combination of these two variables is stationary, then the error-correction modeling rather than the standard Granger-causality test should be employed. Therefore, an ECM was set up to investigate both short- and long-run causality. In the ECM, the first difference of each endogenous variable (electricity consumption and real GDP) was regressed on a period lag of the co-integrating equation and lagged first differences of all the endogenous variables in the system, as shown in Eqs. (1) and (2). The lag lengths, L_{11}, L_{12}, L_{21} and L_{22}, in Eqs. (1) and (2) were chosen by using Akaike's information criterion described in Pantula et al. (1994).[3]

One important point to consider in estimating the ECMs is that there might be a structural break. If there exists any structural break, necessary adjustment to reflect the structural break should be made. The author checked the model stability using CUSUM and CUSUMSQ tests suggested by Brown et al. (1975). The tests are appropriate for time series data and might be used if one is uncertain about when a structural break might have taken place. Moreover, the tests are quite general in that they do not require a prior specification of when the structural break takes place (Greene, 1997, p. 355). The null hypothesis is that the coefficients are the same in every period, i.e. there is no structural break. Table 3 contains the results of the tests. Both tests suggest that the null hypothesis of absence of structural break cannot be rejected at 10% level of significance. Thus, the models are stable over time. It appears that applying Granger-causality tests based on the ECMs described in Eqs. (1) and (2) does not suffer from any problem caused by a structural break.

Table 3
Results of CUSUM and CUSUMSQ tests

	CUSUM test		CUSUMSQ test	
	Test statistic	p-values	Test statistic	p-values
Eq. (1)	0.270	1.000	0.221	0.558
Eq. (2)	0.499	0.644	0.377	0.245

Note: The CUSUM and CUSUMSQ tests are suggested by Brown et al. (1975). The p-values are calculated under the null hypothesis of absence of structural break.

The results of the tests on causality are presented in Table 4. A significance level of 10% is also used for causality tests. Short-run causality is found to run from electricity consumption to real GDP. However, the reverse short-run causality does not exit. That is, there is uni-directional short-run Granger-causality from electricity consumption to economic growth. The coefficient of the ECT is found to be significant in Eq. (2) and not in Eq. (1), which indicates that long-run Granger-causality from real GDP to electricity consumption exists, but the reverse does not.

Results of the significance of the estimated coefficients on lagged values of change in electricity consumption (ΔLEC), along with the ECT in Eq. (1) are consistent with the presence of strong Granger-causality running from electricity consumption to economic growth. These indicate that whenever a shock occurs in the system,

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[3] Finally, $L_{11}=9$, $L_{12}=8$, $L_{21}=8$, and $L_{22}=9$ were derived. More detailed estimation results are omitted here for brevity. However, they are available from the author upon request.

Table 4
Results of causality tests based on the error correction model

	Source of causation				
	Short-run		Long-run	Joint (short-run/long-run)	
	ΔLEC	$\Delta LGDP$	ε_{t-1}	ΔLEC, ε_{t-1}	$\Delta LGDP$, ε_{t-1}
Null hypotheses	*F*-statistics		*t*-statistics	*F*-statistics	
Electricity consumption does not cause economic growth	8.05^{b} (0.030)	—	1.14 (0.318)	7.431^{b} (0.035)	—
Economic growth does not cause electricity consumption	—	3.55 (0.118)	2.41^{a} (0.074)	—	3.15 (0.140)

Note: The lag lengths are chosen by using Akaike's information criterion described in Pantula et al. (1994). The numbers in parentheses below the statistics are *p*-values calculated under the null hypothesis of no causation.
[a,b]Denote the rejection of the null hypothesis at 10% and 5% levels of significance, respectively.

electricity consumption would make short-run adjustments to restore long-run equilibrium. However, the statistical insignificance of the estimated coefficients on lagged values of change in real GDP ($\Delta LGDP$), along with the ECT in Eq. (2) means that there is no strong Granger-causality running from real GDP to electricity consumption. Thus, according to the overall results, we can conclude that there is bi-directional causality between electricity consumption and economic growth.

4. Summary, policy implications and conclusions

The results of this study showed that there are uni-directional short-run causality from electricity consumption to economic growth, uni-directional long-run causality from economic growth to electricity consumption, and uni-directional strong causality from electricity consumption to economic growth. Overall, the author found that causality runs from electricity consumption to economic growth with feedback. This is consistent with Glasure and Lee's (1997) research which dealt with energy consumption including electricity consumption in Korea. The study finding of bi-directional Granger-causality or feedback between electricity consumption and economic growth has a number of implications for policy analysts and forecasters in Korea.

A high level of electricity consumption leads to high level of real GDP. The electricity consumption is the initial receptor of an exogenous impact and the equilibrium is restored through adjustment in the real income variable. This implies that electricity consumption infrastructure shortage may restrain the economic growth in Korea. Increasing real GDP requires enormous electricity consumption, though there are many other factors contributing to economic growth, and electricity is only one of such factors. In order not to adversely affect economic growth, efforts must be made to encourage government and industry to increase electricity supply investment.

A policy for increasing electricity supply investment is, therefore, likely to enhance economic growth for Korea. In pursuit of continuing economic growth, Korea will need to put more efforts into increasing electricity supply investment when implementing national electricity supply infrastructure as a strategy toward advanced development in the long haul. Thus, this study generates confidence in decisions to invest in the electricity supply infrastructure. Furthermore, as implied by Baer et al. (2002), the payoff effect of ICTs on economic growth can be achieved only through a robust national electricity infrastructure that supports ICT adoption and applications.

Moreover, this study lends support to the argument that an increase in real income, ceteris paribus, gives rise to electricity consumption. Economic growth results in a higher proportion of national income spent on highly electricity-consuming goods and/or services such as plasma display panel television and high-speed wired and/or wireless Internet connection, and stimulates further electricity consumption. Intuitively, increased real income requires enormous electricity consumption.

For the newly industrializing countries such as Korea in general, electricity infrastructure is an important ingredient of economic growth. Fast economic growth has boosted the consumption of electricity over the past decades, rising at an annual rate of about 12% between 1970 and 2000. The figure far exceeds the annual growth rate of 6.8% in real GDP during the same period. Electricity now constitutes a critical factor in sustaining the well-being of the Korean people as well as the nation's economic growth. Production in industries such as manufacturing, construction and transportation demands a substantial amount of electricity infrastructure. Therefore, electricity supply side measures in harmony with economic growth are needed. According to the national long-term power development plan, in order not to adversely affect economic growth Korea needs to build four power plants with an installed generation capacity of 1.91 GW every year and double the nation's total power supply every 6 years to meet such a rapidly rising demand for electricity.

In addition to supply side measures, demand side management measures, often referred to as second-hand power generation, are also needed. The electricity intensity (defined as the amount of electricity consumption per GDP) in Korea is 0.57 kWh/USD in 1998. The value is larger than those in the developed countries.[4] High electricity intensity in Korea reflects inefficient electricity usage in industries and/or households, and indicates that there are high electricity saving potentials. The low electricity rates, much less that electricity production cost, established by the government in order to stabilize the general price level of the national economy encourage people to waste electricity. Thus, improving electricity efficiency of electrical appliances and equipment, reducing the loss in power transmission and distribution, and introducing various kinds of tariff reforms such as a summer peak-reduction tariff schedule aiming to control electricity consumption patterns through leveling projected electricity demand and saving supply costs of electricity can induce a high degree of efficiency in the existing facilities, without adversely affecting a high level of electricity consumption for economic growth.

While causal linkages between electricity consumption and economic growth this analysis conclusively demonstrates and the implications of the results may be unique for Korea, it should be stressed that the techniques employed in this study can be readily applied to time series data from other countries and extended to other multivariate systems, where electricity consumption and real income are exposed to be determined by other economic factors such as net fixed capital stock, employment, exports etc. Furthermore, such an analysis could reveal the structural channels by which real income and electricity consumption are inherently causal.

A final caveat is in order. Although bi-directional causality between electricity consumption and economic growth has been found in this study, it has not been possible to fully examine the relationship between the two because how much electricity consumption contributes to economic growth or economic growth to electricity consumption is still unknown. The work of uncovering the relationship remains a useful avenue for future research.

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[4] The electricity intensities in Japan, France, the UK, and the US are 0.31, 0.31, 0.31, and 0.51 kWh/USD in 1998, respectively (International Energy Agency, 2000).