Causal Nexus of Electricity Consumption and Economic Growth: Evidence for Selected Eight Asian Countries

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Introduction

In economic growth empirics, waves of neo-classical theories pioneered by Solow (1956) include capital and labor as variable inputs with technology as total factor productivity. They omitted the essential role of electricity consumption in economic growth enhancement. The seminal work of Kraft and Kraft (1978) that found evidence of a unidirectional causal flow from GNP to electricity consumption in the U.S. for 1947-74 inspired an expanding volume of academic research on this important subject for developing countries.

The empirical findings of these studies are summarized in four classifications: i) growth hypothesis (causality runs from electricity consumption to economic growth), ii) conservation hypothesis (causality flows from economic growth to electricity consumption or its reverse), iii) feedback hypothesis (bi-directional causality between electricity consumption and economic growth), and iv) neutrality hypothesis (absence of causal connection between electricity consumption and economic growth).

The above hypotheses sparked curiosity and interest among economists and policymakers over three decades to investigate the direction of causality between electricity consumption and GDP, income, employment, or energy prices. The primary objective of this study is to explore the direction of causality between electricity consumption and real economic growth for selected eight Asian countries (Bangladesh, India, China, Malaysia, Indonesia, Taiwan, Sri Lanka and Pakistan). To implement this research design, standard unit root tests for data nonstationarity/stationarity, the Johansen-Juselius procedure for I(1) behavior of both variables and the ARDL (Autoregressive Distributed Lag) procedure for different orders of integration of both variables are applied for cointegration, as applicable to individual countries. Finally, vector error-correction models (VECMs) are estimated on the evidence of

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cointegration for long-run causal convergence and short-run interactive feedback dynamics. In the absence of cointegration, the standard Vector Autoregressive (VAR) models are estimated for short-run causality and feedback effects.

The remainder of this paper proceeds as follows. Section II presents a brief review of the related literature. Section III details the empirical methodology. Section IV reports empirical results. Section V offers conclusions and policy implications.

Brief Review of the Related Literature

The empirical evidences in the existing literature are mixed, and inconclusive. They vary across countries, sample periods and empirical methodologies.

To summarize,

i) The studies that found the direction of causality stemming from energy consumption to economic growth include [Yu and Choi (1985), Masih and Masih (1996), Asafu and Adjaye (2000), Yang (2000), Soytas and Sari (2003), Morimoto and Hope (2004), and Narayan and Singh (2007)].

ii) The studies that found unidirectional causality springing from economic growth to energy consumption include [Kraft and Kraft (1978), Cheng and Lai (1997), Glasure and Lee (1998), Cheng (1999), Soytas and Sari (2003), and Narayan and Smyth (2009)].

iii) The studies that found two-way causality include [Masih and Masih (1997), Asafu and Adjaye (2000), Glasure (2002), and Oh and Lee (2004)].

iv) Studies that found no causal relationship between energy consumption and economic growth include [Akarca and Long (1980), Yu and Hwang (1984), Yu and Choi (1985), Erol and Yu (1987), Stern (1993), Paul and Bhattacharya (2004), Cheng (1999), and Imran (2010)].

To elaborate on some of the aforementioned studies, they mostly have tended to focus on Vector Autoregressive (VAR) and Vector Error-Correction (VEC) models in cointegration approach. For example, Masih and Masih (1996) used the cointegration analysis to study the causal relationship between energy consumption in a panel of six Asian countries and found cointegrating relationship between these variables for the cases in India, Pakistan and Indonesia but no cointegration was found in Malaysia, Singapore and the Philippines. The direction of causality is found running from energy consumption to GDP for India, and that running from GDP to energy consumption for Pakistan and the Philippines.

Asafu and Adjaye (2000) investigated the causal relation between energy use and income in four Asian countries using cointegration and error-correction mechanism. They found that causality ran from energy use to income for India and Indonesia. Also, bi-directional causality was detected for Thailand and the Philippines.

The evidences on bi-directional causality are more in common than other cases in the empirical literature. Yang (2000) found bi-directional causality between energy consumption and GDP for Taiwan and these results contradicted with Cheng and Lai (1997) results. Soytas and Sari (2003) found bi-directional causality in Argentina and unidirectional causality running from GDP to energy consumption for Italy and South Korea, and that running from energy consumption to GDP in Turkey, France, Germany and Japan. Paul and Bhattacharya (2004) found bi-directional causality between energy consumption and economic growth for India. Dirck (2008) used the cointegration approach to study the causal relationship between electricity consumption and economic growth for the panel of fifteen European countries. He found cointegration in Great Britain, Greece, Ireland, Italy, and Netherlands, and no cointegration in Austria, Belgium, Germany, Denmark, Spain, Finland, France, Luxembourg, Portugal and Switzerland. He also found a unidirectional causality springing from electricity consumption to GDP for Great Britain, Ireland, Netherland, Spain and Portugal, whereas no causality was found for Austria, Germany, Denmark, Finland, France, Luxembourg, and Switzerland. Narayan, et al., (2010) used the cointegration approach to study the causal relationship between electricity consumption and economic growth for six different panels of ninety three countries. They found bi-directional causal relationship between these two variables except for the panel of the Middle East. However, causality flowing from GDP to electricity consumption was found for the panel of the Middle East in the above study, just mentioned.

Empirical Methodology

First, the time series property of each variable is examined by (ADF) Augmented Dickey-Fuller (Dickey and Fuller, 1981; Fuller, 1996) and KPSS (Kwiattkowski, et al., 1992) tests, although such pre-testing is optional in the Autoregressive Distributed Lag (ARDL) model.

Second, in the event of non- stationarity of time series variables, the most commonly used procedures for ascertaining their cointegrating relationship include the Engle – Granger (1987) residual-based procedure and the Johansen-Juselius (1992, 1999) maximum likelihood-based procedure. Both procedures focus on the cases in which the underlying variables are integrated of order one, I(1). If so, both λ_{trace} and λ_{max} tests can be applied to find cointegration on the evidence of I(1) behavior of each variable. However, it is unlikely in the real world that all countries' macroeconomic variables will depict I(1) behavior. To address the issue of unequal order of integration of non-stationary variables for long-run equilibrium relationship and causal flows, Autoregressive Distributed Lag (ARDL) model or bounds-testing procedure, as suggested by Pesaran et al. (2001) has been used in this study. It is applicable irrespective of whether the regressors in the model are purely I(0), and I(1) or mutually integrated. Another advantage of this approach is that the model takes a sufficient number of lags to capture the data generating process (DGP) in a General-to-Specific (GETS) modeling framework (Laurenceson and Chai, 2003). Third, a dynamic error-correction model (ECM) for long-run causality can also be derived from ARDL procedure through a simple linear transformation (Banerjee et al., 1993). The ECM integrates the short–run dynamics with the long-run equilibrium relationship without losing long-term memory.

Fourth, the ARDL procedure, based on bounds-testing approach, uses the following unrestricted model, as found in (Pesaran and Shin, 1999 and Pesaran, et al., 2001). Assuming a unique long –run relationship among the weakly exogenous independent variables, the following estimating models are specified:

$$\Delta lnGDP_t = \alpha_0 + \sum_{i=1}^{p} b\,\Delta lnGDP_{t-i} + \sum_{i=1}^{p} c\,\Delta lnEL_{t-i} + \lambda_1 lnGDP_{t-1} + \lambda_2 lnEL_{t-1} + \varepsilon_t \ldots(1)$$

$$\Delta lnEL_t = \beta_0 + \sum_{i=1}^{p} b'\Delta EL_{t-i} + \sum_{i=1}^{p} e'\Delta lnGDP_{t-i} + \lambda'_1 lnGDP_{t-1} + \lambda'_2 lnEL_{t-1} + \varepsilon'_1 \ldots\ldots(2)$$

where, GDP = Gross Domestic Product, and EL = Net Electricity Consumption in billion kilowatts (per hour). All first-differenced variables are expressed in natural log. To implement the bounds-testing procedure, the following steps are outlined:

i) for weak exogeneity, Autoregressive Distributed Lag (ARDL) procedure is implemented through VAR pair-wise Granger Causality, and ii) for block exogeneity, Wald Test is applied. Johansen (1988) states that the weak exogeneity assumption influences the dynamic properties of the model and must be tested in the full system framework.

Fifth, equation (1) has been estimated by the Ordinary Least Squares (OLS) in order to test for the existence of a cointegrating relationship among the variables through conducting F-test for the joint statistical significance of the coefficients of the lagged variables in levels. The null and the accompanying alternative hypotheses for the cointegrating relationship are specified as follows:

For equation (1),

Ho: $\lambda_1 = \lambda_2 = 0$ for no cointegration

Ha: $\lambda_1 \neq \lambda_2 \neq 0$ for cointegration

For equation (2),

Ho: $\lambda'_1 = \lambda'_2 = 0$ for no cointegration

Ha: $\lambda'_1 \neq \lambda'_2 \neq 0$ for cointegration

If the calculated F-statistic is above its upper critical value, the null hypothesis of no long-run relationship can be rejected irrespective of the orders of integration for the time series variables. Conversely, if the calculated F-statistic falls below its lower critical value, the null hypothesis cannot be rejected. If the calculated F-statistic falls between its lower and upper critical values, the inference remains inconclusive.

Finally, on the evidence of cointegrating relationship, the following conditional ARDL (p_1, q_1) models are estimated:

$$lnGDP_t = \alpha_0 + \sum_{i=1}^{p1} \alpha_1 \ln GDP_{t-i} + \sum_{i=0}^{q1} \alpha_2 EL_{t-i} + \omega_t \text{.....................(3)}$$

$$lnEL_t = \beta_0 + \sum_{i=0}^{q_1} \beta_1 lnEL_{t-i} + \sum_{i=0}^{p_1} \beta_2 lnGDP_{t-i} + \omega'_t \text{.....................(4)}$$

The optimum lag orders in the above are selected by the Akaike Information Criterion (AIC), as found in Akaike (1969). The optimum number of lags are selected appropriately to reduce residual serial correlation and to avoid overparameterization. According to the recommendation of Pesaran and Shin (1999) for annual data, a maximum of two lags are selected.

For subsequent use in the vector error-correction model, the error-correction term (ECM_{t-1}) is obtained from the following equation:

$$ECM_{t-1} = lnGDP_t - (\widehat{\alpha_0} + \sum_{i=1}^{p1} \widehat{\alpha_1} GDP_{t-i} + \sum_{i=0}^{q1} \widehat{\alpha_2} lnEL_{t-i}) \text{..................(5)}$$

$$ECM'_t = lnEL_t - \left(\hat{\beta}_0 + \sum_{i=1}^{q_1} \hat{\beta}_1 lnEL_{t-i} + \sum_{i=0}^{p_1} \hat{\beta}_2 lnGDP_{t-i}\right) \text{........................ (6)}$$

The short –run and long-run dynamics are captured by estimating the following vector error-correction models:

$$\Delta lnGDP_t = \beta_0 + \sum_{i=1}^{p} \theta_1 \, \Delta \ln GDP_{t-i} + \sum_{i=1}^{p} \theta_2 \, \Delta \ln EL_{t-i} + \psi \, \mathrm{ECM}_{t-1} + \mu_t \text{..................} \quad (7)$$

$$\Delta lnEL_t = \pi_0 + \sum_{i=1}^{q_i} \pi_1 \Delta lnEL_{t-i} + \sum_{i=1} \pi_2 \Delta lnGDP_{t-i} + \psi' ECM'_{t-1} + \mu'_t \text{..................} \quad (8)$$

where, θ's are the coefficients relating to the short –run dynamic elasticities and ψ is the speed of adjustment toward the long-run equilibrium associated with the error-correction term, ECM_{t-1}. The expected sign of $\ddot{\psi}$ is negative. Its statistical significance is reflected through the associated t-value and its numerical magnitude indicates the speed of adjustment toward long-run convergence in equation (7). Likewise, π's reflect short-term dynamics and the expected sign of ψ' is negative. Its statistical significance in equation (8) confirms long-run causal flow and convergence. In the absence of cointegration, the above models are estimated by excluding the respective error-correction terms that collapse into VAR models.

Annual data from 1981 through 2010 are employed in this study. GDP data are obtained from several annual volumes of International Financial Statistics (IFS), published by the IMF (International Monetary Fund). Net electricity consumption data in billion kilowatts (per hour) are obtained from http://tonto.eia.doe.gov/ cfapps/ipdbproject/iedindX3.cfm.

Empirical Results

First, the results for ADF and KPSS tests with orders of integration of both time series variables for individual countries are reported as follows:

Table 1: ADF and KPSS Tests Results and Order of Integration

		ADF			**KPSS**			
Countries	*Variables*	*Level*	*First Differ*	*Second Differ*	*Level*	*First Differ*	*Second Differ*	Cointegration Precedures
Bangladesh	LGDP	4.635533	-0.345571	-4.870659	0.729765	0.653816	0.67340	ARDL
	L Ele	0.222884	-6.192168		0.696556	0.090554		
India	LGDP	1.704999	-2.771239	-5.718762	0.732964	0.358826		Johansen
	L Ele	-1.387959	-3.388931	-6.156508	0.686397	0.273794		
China	LGDP	0.652279	-3.876784		0.734246	0.054770		ARDL
	L Ele	0.118627	-2.742057	-5.124485	0.691377	0.302600		
Malaysia	LGDP	1.847460	-4.720454		0.718146	0.420981	0.187744	ARDL
	L Ele	2.589583	-1.556959	-7.918122	0.672534	0.435664	0.325873	
Indonesia	LGDP	-0.651773	-4.127104		0.7222050	0.123078	0.373639	Johansen
	L Ele	-2.161482	-4.871339		0.686947	0.483615	0.284923	

Taiwan	LGDP	-2.922713	-4.334428		0.718381	0.483808	0.036945	Johansen
	L Ele	-1.022084	-4.823407		0.681884	0.195361	0.240078	
Sri Lanka	LGDP	1.170354	-4.531076		0.735219	0.193604		Johansen
	L Ele	-0.448244	-7.802992		0.694363	0.424055		
Pakistan	LGDP	-2.311315	-3.579252		0.729502	0.320644		Johansen
	L Ele	-3.354856	-4.820201		0.681808	0.451290		

Both variables are found nonstationary, based on both ADF and KPSS tests. They reveal the same order of integration or I(1) behavior for India, Indonesia, Taiwan, Sri Lanka and Pakistan justifying the implementation of the Johansen-Juselius procedure. As a result, λ_{trace} and λ_{max} tests are applied for cointegration in these five countries. For Bangladesh, China and Malaysia, the orders of integration of variables are different. So, the ARDL procedure is applied for these three countries.

Second, the λ_{trace} and the λ_{max} tests results, reported in segments (A) and (B) of Table 2, are respectively as follows:

Table 2A: Computed Values of λ_{trace} Statistic

Hypotheses	*India*	*Indonesia*	*Pakistan*	*Sri Lanka*	*Taiwan*	*0.05 Critical Values*
None (H_0: r = 0)	5.829664	12.59124	27.21762*	9.940424	17.16654*	15.49471
At most 1 (H_0: r ≤ 1)	0.0007769	4.806432*	2.383669	0.808535	4.012546*	3.841466
Trace test indicates cointegrating equations at the 0.05 level *Denotes rejection of the null hypothesis of no cointegration at the 0.05 level						

Table 2B: Computed Values of λ_{max} Statstic

Hypotheses	*India*	*Indonesia*	*Pakistan*	*Sri Lanka*	*Taiwan*	*0.05 Critical Values*
None (H_0: r = 0)	5.829664	7.784811	24.83395*	9.131889	13.15399	14.26460
At most 1 (H_0: r ≤ 1)	0.0007769	4.806432*	2.383669	0.808535	4.012546*	3.841466
λ_{max} test indicates cointegrating equations at the 0.05 level *Denotes rejection of the null hypothesis of no cointegration at the 0.05 level						

As observed in Tables 2(A and B), there are evidences of cointegration for Indonesia, Pakistan and Taiwan in terms of both λ_{trace} and λ_{max} tests. Thus, vector error-correction models (VECMs) (7) and (8) are estimated for these countries. On the other hand, there are no evidences of cointegration for India and Sri Lanka where VAR models are estimated.

Third, ARDL model is implemented for cointegration in the cases of Bangladesh, China and Malaysia, as stated earlier. The estimates are reported as follows:

Table 3: ARDL Estimates

	Bangladesh		**China**		**Malaysia**	
Variables	Coefficients	t-statistic	Coefficients	t-statistic	Coefficients	t-statistic
C	-0.008848	-0.039041	0.188222	2.800019	0.371659	0.713653
lnGDP (-1)	1.004607	28.15090	0.833734	11.50805	0.354549	0.925811
lnELC (-1)	0.007944	0.476691	0.180574	2.218077	0.858711	4.845887

None of the coefficients of the one-period lagged variables in natural log as in equations (1) and (2) is zero for Bangladesh, China and Malaysia confirming cointegration in each country. As a result, the vector error-correction models are estimated for these countries as well.

Fourth, the estimates of the vector error-correction models (VECMs) (7) and (8) are reported as follows:

Table 4: Estimates of VECM (7) with lnGDP as Dependent Variable*

Variables	*Pakistan*	*Indonesia*	*Taiwan*	*Malaysia*	*China*	*Bangladesh*
C	0.030368 (2.670401)	0.052478 (1.953874)	0.012382 (0.579222)	0.037433 (1.786286)	0.039650 (1.519129)	0.005697 (0.749011)
ECM_{t-1}	-0.142890 (-1.967493)	-0.020997 (0.061207)	-0.145211 (-1.294252)	-0.175967 (-1.175799)	-0.027525 (-0.664807)	-0.014713 (-0.357300)
$\Delta lnGDP_{t-1}$	0.192395 (0.919753)	0.270689 (1.179423)	0.253362 (1.052141)	0.123657 (0.461776)	0.806021 (3.994995)	0.762121 (3.403805)
$\Delta lnGDP_{t-2}$	0.192395 (-0.455623)	-0.099111 (-0.434362)	0.349436 (1.458480)	0.012801 (0.045493)	-0.421445 (-2.093505)	0.012011 (0.053273)
$\Delta ln\ EL_t$	0.142393 (2.787878)	0.020530 (0.134175)	0.279868 (2.261836)	1.172266 (1.574492)	0.200525 (0.994889)	0.033569 (1.377122)
$\Delta ln\ EL_{t-1}$	0.028134 (0.552840)	0.089202 (0.610061)	-0.038676 (-0.298066)	-0.879846 (-0.927646)	0.127626 (0.530762)	0.017468 (0.709777)
$\Delta ln\ EL_{t-2}$	-0.006120 (-0.122503)	-0.043268 (-0.300664)	-0.069604 (-0.581154)	0.193305 (0.275908)	-0.121139 (-0.592910)	0.007711 (0.354539)
*Associated t-values are reported within parentheses.						

Table 4 reveals that the coefficient of the error-correction term (ECM_{t-1}) for each country has expected negative sign. But the associated t-value only for Pakistan is statistically significant. For other countries, the associated t-values are statistically insignificant. The aforementioned imply a significant long-run causal flow from electricity consumption to real GDP of Pakistan. A similar inference is statistically weak for other countries. However, there are evidences of net positive short-run interactive feedback effects between variables for all countries, as reported above.

Table 5: Estimates of VECM (8) with lnEL as Dependent Variable*

Variables	*Pakistan*	*Indonesia*	*Taiwan*	*Malaysia*	*China*	*Bangladesh*
C	-0.090380 (-2.107452)	0.087111 (2.198630)	0.055894 (1.628443)	0.001844 (.0285094)	0.016307 (0.514979)	0.084592 (1.301871)
ECM_{t-1}	-0.022507 (-3.618992)	-0.139024 (-0.956910)	-0.362920 (-2.385510)	-0.075482 (-0.72843)	-0.173418 (-1.814901)	-0.243101 (-1.447627)
$\Delta lnEL_{t-1}$	-0.006215 (-0.040964)	0.102131 (0.432733)	0.121399 (0.580791)	0.606455 (2.540915)	0.627432 (2.750994)	-0.150796 (-0.680011)
$\Delta lnEL_{t-2}$	0.083136 (0.559614)	0.132288 (0.588854)	0.125284 (0.642836)	0.005284 (0.026542)	0.275000 (1.185650)	-0.077525 (-0.397005)
$\Delta lnGDP_{t-1}$	0.016498 (0.025398)	0.029801 (0.080682)	-0.539614 (-1.375594)	0.129346 (1.851105)	-0.365176 (-1.329946)	-2.657937 (-1.073097)
$\Delta lnGDP_{t-2}$	0.556765 (0.892462)	-0.179913 (-0.488507)	-0.316816 (-0.769119)	-0.100924 (-1.319091)	-0.141435 (-0.589724)	0.636026 (0.316240)
*Associated t-values are reported within parentheses.						

For Pakistan, Taiwan and China, there are strong evidences of statistically significant long-run causal flow from GDP to electricity consumption, as confirmed by the negative coefficient of the respective error-correction term (ECM_{t-1}) and the associated t-value. For other countries, such evidences are remotely significant in statistical sense. However, there exist net positive interactive feedback effects for all the above countries in the short run.

Finally, VAR models are estimated for short-fun bi-directional causality and interactive feedback effects. The results for India and Sri Lanka are reported as follows:

Table 6: VAR Estimates*

LnGDP as Dependent Variable			lnEL as Dependent Variable		
Variables	India	Sri Lanka	Variables	India	Sri Lanka
C	0.025795 (1.530152)	0.029986 (1.999853)	C	0.035525 (1.557107)	0.050743 (1.047493)
$\Delta lnGDP_{t-1}$	0.600498 (2.638162)	0.139927 (0.603349)	$\Delta lnEL_{t-1}$	0.329944 (1.551541)	-0.544929 (-2.468557)
$\Delta lnGDP_{t-2}$	-0.084799 (-0.332568)	0.102351 (0.436201)	$\Delta lnEL_{t-2}$	0.243619 (1.156446)	-0.188245 (-0.832896)
$\Delta lnEL_{t-1}$	-0.154083 (-0.948840)	-0.004354 (-0.052313)	$\Delta lnGDP_{t-1}$	0.220365 (0.620873)	0.590064 (0.847194)
$\Delta lnEL_{t-2}$	0.087246 (0.547737)	0.006152 (0.081075)	$\Delta lnGDP_{t-2}$	-0.606094 (-1.899371)	0.228678 (0.321037)
*Associated t-values are reported within parentheses.					

Table 6 reveals short-run bi-directional causality for both India and Sri Lanka with net positive interactive feedback effects as the respective sum of the lagged co-efficients of variables for each country is positive.

Conclusions and Policy Implications

In light of the ADF test and the KPSS test results as well as I(1) behavior of each time series variable, the Johansen-Juselius procedure for cointegration is applied in the cases of India, Indonesia, Pakistan, Sri Lanka and Taiwan. Among these countries, cointegration is not found for India and Sri Lanka. For them, VAR models are estimated. For Indonesia, Pakistan and Taiwan, VECMs are implemented. For nonstationarity in each time series variable and different orders of integration, the ARDL procedure is applied in the cases of Bangladesh, China and Malaysia. On the evidence of cointegration, VECMs are estimated for them as well.

The estimates of VECMs and VARs are summarized in Table 7 as follows:

Table 7: Summary Results of VECMs and VARs

Country	*Long-Run Causal Flows*	*Net Feedback Effects*
	VECMs	
Pakistan	Bidirectional (strong)	Positive
Indonesia	Bidirectional (weak)	Positive
Taiwan	Bidirectional (stronger reverse causality)	Positive
Malaysia	Bidirectional (weak)	Positive
China	Bidirectional (stronger reverse causality)	Positive
Bangladesh	Bidirectional (weak)	Positive
	VAR's	
India	Bidirectional (Granger causality)	Positive
Sri Lanka	Bidirectional (Granger causality)	Positive

In brief, the evidences on long-run causality and convergence are weakly bi-directional in all cases except Pakistan. However, for some countries, reverse causality is relatively stronger, though statistically not so significant. There are evidences of short-run net positive interactive feedback effects. For India and Sri Lanka, there are evidences of bi-directional Granger causality with net positive interactive feedback effects.

For policy implications, since higher real GDP growth requires larger electricity consumption, adequate, timely, and uninterrupted increasing supply of electricity is a pre-condition to maintain and to enhance the economic growth momentum. The government of each sampled country must closely monitor the surging demand for electricity following real GDP growth momentum and invest in advance to generate its additional supply to match such excess demand. Otherwise, the economic growth momentum is destined to be unsustainable in each country regardless of the mixed empirical evidences in this study. In closing, policy implications are likely to vary from one country to another country.

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