

Empirical evidence regarding electricity consumption and urban economic growth

Thomas M. Fullerton Jr & Adam G. Walke

To cite this article: Thomas M. Fullerton Jr & Adam G. Walke (2019) Empirical evidence regarding electricity consumption and urban economic growth, *Applied Economics*, 51:18, 1977-1988, DOI: [10.1080/00036846.2018.1529405](https://doi.org/10.1080/00036846.2018.1529405)

To link to this article: <https://doi.org/10.1080/00036846.2018.1529405>



Published online: 13 Oct 2018.



Submit your article to this journal [↗](#)



Article views: 30



View Crossmark data [↗](#)



Empirical evidence regarding electricity consumption and urban economic growth

Thomas M. Fullerton Jr and Adam G. Walke

Department of Economics & Finance, University of Texas at El Paso, El Paso, TX, USA

ABSTRACT

Links between electricity consumption and economic growth are fairly well documented for national economies, but less so for urban economies. The analysis of such relationships at the sub-national level of aggregation can potentially offer a useful complement to national-level research. This study examines the electricity-growth nexus in El Paso, Texas, while also considering the roles of capital stocks and employment. Testing suggests the presence of cointegrating relationships and a vector error correction model is estimated. Granger causality tests reveal the absence of causality between electricity consumption and personal income, implying that energy conservation efforts will have a neutral effect on economic growth. Furthermore, the results indicate that causality runs from the capital stock and employment to both personal income and electricity consumption. This echoes previous research regarding the importance of accounting for capital and labour factors of production in studies of aggregate electricity utilization and economic performance. The methodology used in this analysis to develop a broad synthetic measure of the urban capital stock, including various categories of public infrastructure, can also be applied to other regions and urban economies.

KEYWORDS

Energy-growth nexus; capital stocks; regional economic development; electricity consumption; Granger causality

JEL CLASSIFICATION

O40; Q41; R10

1. Introduction

The relationship between electricity consumption and economic growth, sometimes called the electricity-growth nexus, has been widely studied at the national level. Research in this area has focused on determining the direction of causality between electricity and growth. The results are diverse, varying by region of the world examined, stage of economic development, and other factors (Ozturk 2010; Omri 2014). The electricity-growth nexus at the regional or metropolitan sub-national levels has, in contrast, received substantially less attention in the literature to date.

This study examines the energy-growth nexus for El Paso, Texas, a mid-sized urban economy located in the southwestern United States. The metropolitan area is served by El Paso Electric, an investor-owned company that provides electric energy for approximately 400,000 accounts. A majority of the company's retail electricity sales in 2015 were to customers located in the vicinity of El Paso, Texas, with a smaller portion of sales to customers in nearby Las Cruces, New Mexico (EPEC 2016). This analysis focuses on electricity consumption in the former area. One reason for focusing on the El Paso

urban area is the existence of consistent data spanning the period from 1976 to 2015 on local public and private capital stocks. Prior research on energy-growth causality indicates that it is important to control for the capital stock as one of the key factors mediating the interaction between energy usage and output (Ghali and El-Sakka 2004; Hamdi, Sbiba, and Shahbaz 2014; He, Fullerton, and Walke 2017).

There are at least two important reasons to examine the interactions between electricity consumption and personal income growth at the metropolitan scale. First, because income and electricity usage patterns vary substantially across regions, metropolitan data sets may be less heterogeneous than national data samples (Gill and Ellison 1976; Fullerton, Macias, and Walke 2016). Along that same line of reasoning, results obtained using data for individual urban economies may also prove more reliable because those outcomes are obtained with data that have not been aggregated across multiple regions.

Second, local governments and businesses with limited market areas have long had an interest in regional-level economic analysis (Klein, 1969). This

observation is perhaps especially pertinent to electricity markets. Electricity generation and distribution are often handled by public or private entities within well-defined regional service areas. Many of the decisions regarding electricity rates and conservation policies for those service areas are made at the regional level. Regional decision-making bodies also have a role in formulating economic development strategies. In the case of El Paso Electric, a metropolitan scale analysis is appropriate because the company's service area is dominated by a single large urban area, El Paso. In this context, urban electricity consumption-income relationships are likely to have direct bearing on the decisions of regional policymakers and planners. For similar reasons, some previous studies have examined electricity consumption dynamics in single metropolitan economies (Al-Shakarchi and Ghulaim 2000; Wangpattarapong et al. 2008; Izquierdo et al. 2011; He, Fullerton, and Walke 2017).

The next section provides a brief review of prior research on the electricity-growth nexus, with attention primarily directed to the hypotheses analysed in that branch of the literature. The subsequent section describes the unit root, cointegration, and Granger causality testing procedures employed for this analysis. Overall characteristics of the data utilized in the 40-year sample assembled for the study are also discussed. The steps followed largely replicate the procedures used in He, Fullerton, and Walke (2017) to examine the electricity-growth nexus in Guangzhou, China. However, in contrast to that earlier study, this analysis develops a multifaceted capital stock series using multiple sources of information. It also examines an urban economy in a high-income, rather than middle-income, country. The latter is pertinent because causal relationships between energy and growth may vary across countries in different stages of economic development (Huang, Hwang, and Yang 2008). Empirical results are subsequently summarized, followed by concluding remarks and policy implications.

II. Literature review

The direction of causality between electricity utilization and income growth has implications for environmental conservation policies and economic development strategies. If electricity consumption

levels have neutral effects on economic growth, this suggests that countries can implement conservation policies without risking economic deceleration (Kalimeris, Richardson, and Bithas 2014). On the other hand, causality running from electricity consumption to growth suggests that there may be trade-offs between economic development and conservation objectives. Because the direction of causality has important practical implications, substantial attention has been devoted to this line of research. These efforts typically examine four general hypotheses.

First, the *growth hypothesis* asserts that unidirectional causality runs from electricity consumption to GDP. Evidence for the growth hypothesis has been documented for Turkey (Altinay and Karagol, 2005), Europe (Ciarreta and Zarraga 2010), former Soviet republics (Bildirici and Kayıkçı 2012), China (Cheng, Wong, and Wu, 2013), and Nigeria (Iyke 2015), in addition to many other areas of the world. Yuan et al. (2007) report unidirectional causality running from electricity consumption to real GDP in the short run. These findings are consistent with the argument that energy represents an important factor of production (Stern 2000). Many production processes require fuel and electricity inputs and those processes, in turn, underlie aggregate economic growth. Evidence for the growth hypothesis would suggest that disruptions in the energy supply have adverse impacts on economic performance.

Second, the *conservation hypothesis* holds that causality runs from GDP to electricity consumption. Evidence in favour of this hypothesis has been uncovered for India (Ghosh 2002), Turkey (Halicioglu 2007), Bangladesh (Mozumder and Marathe 2007), Taiwan (Pao 2009), and Pakistan (Jamil and Ahmad 2010; Shahbaz and Feridun 2012), among other countries. In a study conducted using data for Australia, Narayan and Smyth (2005) find evidence of unidirectional causality running from income to electricity consumption in the long run and somewhat weaker evidence of a parallel line of causality in the short run. Jumbe (2004) reports that, in the short run, changes in Malawi's GDP cause changes in national electricity consumption, as predicted by the conservation hypothesis.

Third, the *feedback hypothesis* posits bi-directional causality between electricity usage and economic growth. Karanfil and Li (2015) find evidence in support of the feedback hypothesis in many world

regions. Some national-level studies reach the same conclusion for countries such as Korea (Yoo 2005), Burkina Faso (Ouédraogo 2010), Malaysia (Tang and Tan 2013), Angola (Solarin and Shahbaz 2013), Portugal (Tang, Shahbaz, and Arouri 2013), and Bahrain (Hamdi, Sbia, and Shahbaz 2014). Cheng-Lang, Lin, and Chang (2010) find evidence of bi-directional causality between total electricity consumption and real GDP in Taiwan. In a study using data for Central America, Apergis and Payne (2012) report the existence of feedback relationships between economic growth and both renewable and non-renewable electricity consumption in the long run. These studies suggest that economic growth and aggregate electricity utilization, like other macroeconomic variables, have complex, interdependent relationships.

Fourth, the *neutrality hypothesis* posits that there is no causal linkage between economic growth and electricity consumption. The evidence in favour of electricity-growth neutrality also encompasses a wide variety of national data sets. In a study of Middle Eastern and North African countries, Ozturk and Acaravci (2011) document that, in most cases, causal relationships between electricity consumption and growth are absent. Furthermore, a number of multi-country studies find evidence in favour of the neutrality hypothesis for specific sub-groups of countries (Chen, Kuo, and Chen 2007;

Narayan and Prasad 2008; Wolde-Rufael 2014; Cowan et al. 2014). As with the conservation hypothesis, the neutrality hypothesis implies that electricity conservation efforts are not likely to stymie economic growth.

The studies cited above analyse the linkages between electricity consumption and economic growth using aggregate data at the national level. A much smaller body of research has explored similar dynamics using data for sub-national geographic regions. Saunoris and Sheridan (2013) examine the electricity demand-growth nexus for the 48 contiguous states of the United States. The conservation hypothesis is confirmed in the long-run for the aggregate data sample. However, the short-run results generally provide support for the growth hypothesis. At the metropolitan level, He, Fullerton, and Walke (2017) examine the relationship between electricity consumption and economic growth in Guangzhou, China, from 1950 to 2013. The growth hypothesis is confirmed using first-differenced data and the results suggest that a reliable electricity supply is critical to economic growth in this metropolitan area.

In a review of previous research on the electricity-growth nexus, Omri (2014) reports that 40 percent of the studies analysed provide empirical evidence in favour of the growth hypothesis, 33 percent support the feedback hypothesis, and 27 percent are consistent with the conservation hypothesis. Table 1

Table 1. Summary of electricity-growth nexus studies for national economies.

Source	Country	Period	Causal linkages
Ghosh (2002)	India	1951–1997	$Y \rightarrow E$
Jumbe (2004)	Malawi	1970–1999	$Y \rightarrow E$ (short run) $E \leftrightarrow Y$ (long run)
Altinay & Karagol (2005)	Turkey	1950–2000	$E \rightarrow Y$
Narayan and Smyth (2005)	Australia	1966–1999	$Y \rightarrow E$
Yoo (2005)	South Korea	1970–2002	$E \leftrightarrow Y$
Halicioglu (2007)	Turkey	1968–2005	$Y \rightarrow E$
Mozumder and Marathe (2007)	Bangladesh	1971–1999	$Y \rightarrow E$
Yuan et al. (2007)	China	1978–2004	$E \rightarrow Y$ (short run) $E \leftrightarrow Y$ (long run)
Pao (2009)	Taiwan	1980–2007	$Y \rightarrow E$
Cheng-Lang, Lin, and Chang (2010)	Taiwan	1982–2008	$E \leftrightarrow Y$ (aggregate)
Jamil and Ahmad (2010)	Pakistan	1960–2008	$Y \rightarrow E$ (aggregate)
Ouédraogo (2010)	Burkina Faso	1968–2003	$E \leftrightarrow Y$
Shahbaz and Feridun (2012)	Pakistan	1971–2008	$Y \rightarrow E$
Cheng, Wong, & Wu (2013)	China	1953–2010	$E \rightarrow Y$
Saunoris and Sheridan (2013)	United States (nationwide)	1970–2009	$E \rightarrow Y$ (short run) $Y \rightarrow E$ (long run)
Solarin and Shahbaz (2013)	Angola	1971–2009	$E \leftrightarrow Y$
Tang, Shahbaz, and Arouri (2013)	Portugal	1974–2009	$E \leftrightarrow Y$
Tang and Tan (2013)	Malaysia	1970–2009	$E \leftrightarrow Y$
Hamdi, Sbia, and Shahbaz (2014)	Bahrain	1980–2010	$E \leftrightarrow Y$
Iyke (2015)	Nigeria	1971–2011	$E \rightarrow Y$

Note: Y is aggregate output, E is aggregate electricity consumption, and arrows represent the implied direction of causality.

summarizes the findings of above-cited studies that are specific to individual countries. The countries and time periods examined are noted, along with the major conclusions of each work. Nine of these studies are consistent with the conservation hypothesis in either the short- or long-run. However, eleven studies find that electricity consumption influences economic growth, either in a unidirectional fashion or as part of a bi-directional feedback relationship. The latter results suggest that, in a majority of the cases considered, there is a trade-off between attaining conservation goals and reaching economic growth objectives.

Subsequent sections of this study contribute to this branch of the energy economics literature by analysing the direction of causality between metropolitan electricity consumption and income for an urban area in the United States. In particular, these relationships will be analysed for a mid-sized metropolitan economy, El Paso, Texas, for the period from 1976 to 2015. Relatively few prior studies have examined the electricity-growth nexus at the metropolitan level. Another contribution of this research is that it takes into account both private capital stocks and public infrastructure, including the following capital asset types: streets, highways, waterworks, and an airport. This analysis may help shed light on urban economic performance, as well as provide evidence that is useful for regional public policy debates surrounding electricity supply, energy conservation, infrastructure, and sustainable economic development strategies.

III. Data and methodology

Prior studies often control for variables that may influence the relationship between energy consumption and economic growth. In particular, a number of studies use a Cobb-Douglas aggregate production function including labour and capital inputs (Stern 2000; Lee, Chang, and Chen 2008; Shahbaz, Zeshan, and Afza 2012; Hamdi, Sbia, and Shahbaz 2014). This effort follows the same general approach. In a review of previous work in this area, Ozturk (2010) highlights the importance of including control variables such as factors of production in models used for testing the direction of causality between energy consumption and economic growth.

Some scholars have suggested that energy should be included in aggregate production functions. Stern (2000) finds that energy is a limiting factor to output growth in the United States. Ghali and El-Sakka (2004) obtain similar results for Canada. The argument advanced by these and other scholars is that energy is essential to transforming labour and capital inputs into output. However, other studies such as Payne (2009) suggest that changes in energy consumption have little or no effect on GDP. To assess whether electric energy contributes to regional income growth, the analysis takes as its starting point the aggregate production function shown in Equation (1).

$$Y = AK^{\beta_1}L^{\beta_2}E^{\beta_3} \quad (1)$$

In Equation (1), Y represents real income, A is a technology index, K is the real capital stock, net of depreciation, L is total employment, E is electricity consumption, and the exponents are parameters. Transforming both sides of Equation (1) using natural logarithms yields Equation (2). The specification that underlies the empirical analysis below is shown in Equation (3), where lower-case letters represent variables that have been logarithmically transformed and u is a random error term.

$$\ln(Y) = \ln(A) + \beta_1 \ln(K) + \beta_2 \ln(L) + \beta_3 \ln(E) \quad (2)$$

$$y = \beta_0 + \beta_1 k + \beta_2 l + \beta_3 e + u \quad (3)$$

Equation (3) provides a framework for determining which variables to include in the analysis. However, due to the nature of the research question at hand, the direction of causality implicit in Equation (3) cannot be assumed *a priori* but, instead, must be determined by empirical testing. The procedure employed for this purpose is a Granger causality test.

The initial step of the statistical analysis involves testing the logarithmically transformed variables for stationarity. Three unit root tests are employed for this purpose: Augmented Dickey Fuller (ADF), Phillips-Perron (PP), and Kwiatkowski-Phillips-Schmidt-Shin (KPSS). However, in the presence of structural breaks, standard unit root tests are biased towards accepting the unit root hypothesis even if the series is, in fact, stationary in the periods before and after the breakpoint (Enders 2010). To accommodate the possibility of structural change in the

data series, the analysis also employs the Perron (1989) unit root test allowing for a one-time structural break. The Akaike Information Criterion (AIC) is used to select lag orders for both tests and for the subsequent tests described below.

If the data series have the same order of integration, further tests are conducted to determine whether cointegrating relationships exist among the variables. First, the Johansen (1991, 1995) trace test and maximum eigenvalue test are used to assess the cointegrating rank. Second, to allow for the possibility of structural breaks in cointegrating relationships between variables, the Gregory-Hansen (1996) test is also applied. The latter test allows for changes in both the intercept and slope of the cointegrating equations. This test is used as a check on the Johansen cointegration test results.

If cointegration is detected between the variables under analysis, a vector error correction procedure is implemented. A number of previous investigations of causal relationships between electricity and growth employ vector error correction methodologies (e.g. Tang, Shahbaz, and Arouri 2013; Hamdi, Sbia, and Shahbaz 2014; Iyke 2015). The structure of the vector error correction model is shown in Equations (4) through (7). The α error correction coefficients multiply the lagged residuals from the long-run cointegrating equations, denoted v_{kt-1} , where the subscript k denotes the cointegrating vectors. The number of cointegrating vectors is determined on the basis of the Johansen and Gregory-Hansen tests. All other variables appear in first-differenced form, where Δ is the difference operator. Lags are denoted by j and the optimal lag order is selected for the system of equations on the basis of AIC values.

$$\begin{aligned}\Delta y_t = & \mu_1 + \sum \alpha_{1k} v_{kt-1} + \sum \theta_{11j} \Delta y_{t-j} \\ & + \sum \theta_{12j} \Delta k_{t-j} + \sum \theta_{13j} \Delta l_{t-j} \\ & + \sum \theta_{14j} \Delta e_{t-j} + u_{1t}\end{aligned}\quad (4)$$

$$\begin{aligned}\Delta k_t = & \mu_2 + \sum \alpha_{2k} v_{kt-1} + \sum \theta_{21j} \Delta y_{t-j} \\ & + \sum \theta_{22j} \Delta k_{t-j} + \sum \theta_{23j} \Delta l_{t-j} \\ & + \sum \theta_{24j} \Delta e_{t-j} + u_{2t}\end{aligned}\quad (5)$$

$$\begin{aligned}\Delta l_t = & \mu_3 + \sum \alpha_{3k} v_{kt-1} + \sum \theta_{31j} \Delta y_{t-j} \\ & + \sum \theta_{32j} \Delta k_{t-j} + \sum \theta_{33j} \Delta l_{t-j} \\ & + \sum \theta_{34j} \Delta e_{t-j} + u_{3t}\end{aligned}\quad (6)$$

$$\begin{aligned}\Delta e_t = & \mu_4 + \sum \alpha_{4k} v_{kt-1} + \sum \theta_{41j} \Delta y_{t-j} \\ & + \sum \theta_{42j} \Delta k_{t-j} + \sum \theta_{43j} \Delta l_{t-j} \\ & + \sum \theta_{44j} \Delta e_{t-j} + u_{4t}\end{aligned}\quad (7)$$

The final step in the analysis is Granger causality testing. Both the t -statistics on the error correction coefficients and Wald χ^2 tests for the coefficients on differenced variables can be used to assess the existence of causal relationships between variables in the system. Wald tests help evaluate the null hypothesis that Granger causality does not exist between a pair of variables. Of particular importance is the null hypothesis that that changes in electricity consumption do not reliably lead changes in income, i.e. $H_0: \Sigma \theta_{14j} = 0$, and the hypothesis that fluctuations in income do not reliably precede variations in electricity consumption, i.e. $H_0: \Sigma \theta_{41j} = 0$. Also, the t -statistics for the lagged error correction terms provide additional evidence regarding causality. Under the null hypothesis of no-causality, the error correction coefficients are statistically indistinguishable from zero (Lütkepohl and Krätzig 2004). The results of Granger causality tests help identify which of the hypotheses articulated in the previous section are substantiated for the El Paso metropolitan economy.

In order to test the hypotheses regarding electricity-growth relationships in this regional economy, data are collected on income, capital stocks, employment, and electricity consumption. Table 2 provides descriptions and units of measure for each of these variables. Data on electricity sales, in megawatt hours, are collected from El Paso Electric Company. The El Paso Electric service area stretches from Hatch, NM all the way to Van Horn, TX. From

Table 2. Mnemonics and variable definitions.

Variable	Definition	Units
Y	Real personal income	Thousands of 2009 dollars
K	Stock of public, industrial, and commercial capital	Thousands of 2009 dollars
L	Total employment	Thousands of Jobs
E	El Paso Electric Co. billed electricity sales in Texas	Megawatt hours

Note: Sample data period: 1976 – 2015.

1980 to 2015, company data are disaggregated by state and indicate that the Texas segment of the service area generally accounts for approximately 80 percent of total system usage. Prior to 1980, only total consumption data by customer category are available for the full service area. The correlation coefficient for Texas and area-wide electricity usage is 0.9992. Given that, total kilowatt hour sales are used to estimate Texas kilowatt hours for years prior to 1980. Data from the El Paso Electric annual report (EPEC 1981) are used to interpolate consumption in each customer category individually from 1976 to 1979 (Friedman 1962; Fernandez 1981).

The private capital stock is approximated by the appraised value of privately-owned commercial and industrial structures. The private capital stock data are acquired from the El Paso Central Appraisal District. Data on public infrastructure are obtained from financial reports and data provided by the City of El Paso and from the Texas Department of Transportation. Specifically, data are collected on the value of investment in the following capital assets: highways, city streets, water and sewer systems, and El Paso International Airport. The initial-year capital stocks for each of the latter are estimated using the optimal consistency method of Albala-Bertrand (2010). The subsequent evolution of the capital stock series, K , is governed by the formula, $K_t = K_{t-1}(1-d) + I_t$, where d is the rate of depreciation and I is investment. Depreciation rates of 2.02 and 1.52 percent are applied for streets and non-building government structures respectively (USDC 2003). Because only 40 observations are included in the sample, the public and private capital stocks are aggregated into a single variable to save degrees of freedom.

Similar to Saunoris and Sheridan (2013), real personal income data are used to quantify economic

Table 3. Descriptive statistics.

Variable	Y	K	L	E
Mean	14,375,608	7,267,795	301,059	4,249,731
Standard Deviation	5,548,032	3,262,306	70,287	1,211,100
Maximum	24,862,875	14,525,137	423,596	6,146,814
Minimum	6,465,715	3,256,465	189,986	2,447,714
Observations	40	40	40	40

Note: Sample data period: 1976 – 2015.

growth. Data on the GDP price deflator, El Paso employment, and El Paso personal income are obtained from the Bureau of Economic Analysis. Data on income and the capital stock are expressed in real terms using the GDP price deflator. The sample size is constrained by the capital stock series, which begins in 1976. A total of 40 years of data are used for the analysis. Table 3 shows summary statistics for all variables prior to transformation using natural logarithms. Total aggregate electricity consumption for the region more than doubled over the course of the sample period, while real personal income and the stock of commercial, industrial, and public capital grew at substantially more rapid rates.

IV. Empirical results

Table 4 reports the results of three types of unit root tests. The ADF and PP tests evaluate the unit root null hypothesis. The KPSS test, in contrast, posits a null hypothesis of stationarity (Kwiatkowski et al. 1992). Regardless of the testing procedure utilized, the results of the tests suggest that all four variables are non-stationary in level form and stationary after first-differencing. As a further check on these results, modified Dickey-Fuller tests are conducted that allow for the possibility of structural breaks in the data (Perron 1989). The results of this latter test,

Table 4. Unit root test results.

	Augmented Dickey-Fuller (ADF)		Phillips-Peron (PP)		Kwiatkowski-Phillips-Schmidt-Shin (KPSS)	
	H_0 : Unit root		H_0 : Unit root		H_0 : Stationarity	
	t-statistic	5% critical values	Adjusted t-statistic	5% critical values	LM-statistic	5% critical value
y	-1.513876	-2.938987	-2.764315	-2.938987	0.778199*	0.463000
k	1.013450	-2.938987	1.086216	-2.938987	0.775233*	0.463000
l	-1.560314	-2.938987	-1.749760	-2.938987	0.777812*	0.463000
e	-1.793680	-2.938987	-1.168115	-2.938987	0.761002*	0.463000
Δy	-7.328506*	-2.941145	-7.360094*	-2.941145	0.299104	0.463000
Δk	-6.292524*	-2.941145	-6.310753*	-2.941145	0.201563	0.463000
Δl	-5.293760*	-2.941145	-5.242440*	-2.941145	0.207553	0.463000
Δe	-7.776965*	-2.941145	-7.736697*	-2.941145	0.248804	0.463000

Note: Asterisks indicate rejection of the null hypothesis using a 5-percent significance criterion.

Table 5. Perron modified ADF unit root test results.

Variables	t-statistic	5% critical values	Variables	t-statistic	5% critical values
y	-3.423413	-4.443649	Δy	-8.437928	-4.443649
k	-1.083995	-4.443649	Δk	-8.545101	-4.443649
l	-2.185993	-4.443649	Δl	-6.284242	-4.443649
e	-3.475386	-4.443649	Δe	-9.371399	-4.443649

shown in Table 5, confirm the conclusion that all of the variables are integrated of order one. The similarity of these results suggests that structural changes are of limited importance for conclusions regarding stationarity in the data sample utilized for this study.

Given that the variables are integrated of the same order, cointegration testing is conducted. The results of the Johansen cointegration test are sensitive to the vector autoregressive lag order. Computed AIC values for a vector autoregressive model estimated in levels reach a minimum at a lag order of five years. That corresponds to a lag order of four years for data expressed in first-differences. The lag lengths selected on the basis of AIC values are used for both the cointegration testing procedure and the subsequent modelling exercise. The results of the Johansen cointegration test are shown in Table 6. Both the trace test and the maximum eigenvalue test strongly suggest the existence of at most two cointegrating vectors. The results shown allow for a linear deterministic trend in the data but conclusions regarding the number of cointegrating vectors are the same regardless of the trend specification employed.

To check the robustness of the cointegration results obtained using the Johansen test, the Gregory-Hansen cointegration test is also deployed. The latter allows for the presence of structural breaks in the long-run relationships between variables. The results shown in Table 7 allow for regime shifts in the cointegrating equations, consisting of changes in both the intercept and the slope coefficients. When electricity consumption is considered as the left-hand-side variable, both the t -statistic and

Table 6. Johansen cointegration test results.

Hypothesized number of cointegrating equations	None	At most one	At most two	At most three
Trace statistic	115.1023	41.60216	7.769806	0.467469
5% critical value	47.85613	29.79707	15.49471	3.841466
p -value	0.0000	0.0014	0.4903	0.4942
Maximum eigenvalue stat.	73.50011	33.83235	7.302338	0.467469
5% critical value	27.58434	21.13162	14.26460	3.841466
p -value	0.0000	0.0005	0.4540	0.4942

Table 7. Gregory-Hansen cointegration test results.

Equation	$y = f(k, l, e)$	$k = f(y, l, e)$	$l = f(y, k, e)$	$e = f(y, k, l)$
ADF t -statistic	-5.852073	-5.623936	-4.926832	-7.342620
Z_t -statistic	-5.928574	-5.697455	-4.062174	-7.528138
5% critical value	-6.00	-6.00	-6.00	-6.00
Z_t -statistic	-37.95322	-37.16812	-23.99572	-40.30386
5% critical value	-68.94	-68.94	-68.94	-68.94

Note: Critical values are from Gregory and Hansen (1996).

Z_t -statistic indicate the presence of cointegration at the 5 percent significance level. Likewise, when income is considered as the left-hand-side variable, the same statistics indicate a cointegrating relationship at the 10 percent level of significance, but not at the 5 percent level. Although these results are somewhat less clear-cut than those from the Johansen test, they are generally consistent with the conclusion that cointegrating relationships are present among the variables analysed.

Given the general agreement between the Johansen and Gregory-Hansen procedures regarding the presence of cointegration, a vector error correction model is estimated. On the basis of the AIC results described above, a lag order of four is selected for the first-differenced variables in the short-run equation. Two cointegrating vectors are estimated based on the results above and are normalized on electricity consumption and income. The error correction terms from the estimated equations are reported in Table 8, where α_1 represents the coefficients on the lagged error terms from the cointegrating equation for electricity consumption and α_2 represents the coefficients on the lagged residuals for the long-run income equation. Lagrange Multiplier tests for serial correlation indicate that the residuals of the error correction model are not autocorrelated.

Based on the coefficients in the estimated short-run equation, Granger-causality tests are then conducted. The results, which are shown in Table 9, indicate unidirectional Granger causality flowing from the capital stock and total employment to

Table 8. Error correction terms.

	Left-hand-side variables			
	Δe_t	Δy_t	Δk_t	Δl_t
α_1	-1.105515 (-3.31720)	-0.046076 (-0.32187)	-0.319931 (-1.05446)	-0.111838 (-0.54563)
α_2	-0.070130 (-0.16796)	-1.529253 (-8.52665)	0.460418 (1.21122)	-0.330357 (-1.28643)

Note: The numbers in parentheses are t -statistics.

Table 9. Granger causality analysis.

Left-hand-side variables	Chi-squared statistics			
	$\Sigma \Delta y_{t-j}$	$\Sigma \Delta k_{t-j}$	$\Sigma \Delta l_{t-j}$	$\Sigma \Delta e_{t-j}$
Δy_t	-	15.40762 (0.0039)	50.17374 (0.0000)	1.370019 (0.8494)
Δk_t	6.892876 (0.1417)	-	2.009008 (0.7341)	0.425615 (0.9803)
Δl_t	0.775112 (0.9418)	3.218019 (0.5220)	-	0.908192 (0.9234)
Δe_t	5.181554 (0.2692)	11.35827 (0.0228)	8.744139 (0.0678)	-

Note: The numbers in parentheses are *p*-values.

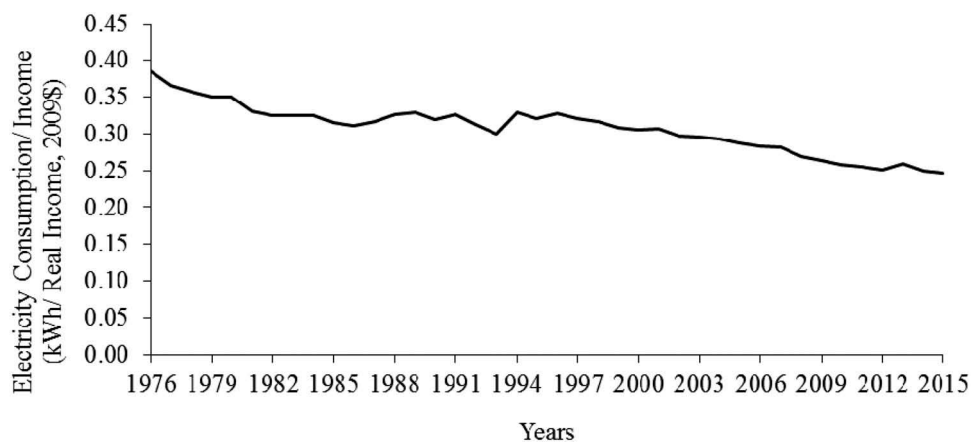
both income and electricity consumption. However, no causal linkages are detected between electricity consumption and income. The latter is consistent with the neutrality hypothesis and implies that energy conservation efforts are not likely to inhibit metropolitan economic growth. The results also align with the finding of Huang, Hwang, and Yang (2008), in a similar causality analysis for countries at multiple stages of development, that conservation efforts are unlikely to hamper growth in high-income countries. The error correction coefficients in Table 8 likewise corroborate the neutrality hypothesis. Overall, these results suggest that there is no causal relationship between electricity consumption and personal income growth for this metropolitan economy.

Several previous, national-level studies of the energy-growth nexus in the United States have found evidence in favour of the neutrality hypothesis (Yu and Hwang 1984; Yu and Jin 1992; Chiou-Wei, Chen, and Zhu 2008; Payne 2009). The absence of causal linkages from electric energy use to economic growth in the El Paso metropolitan economy may reflect national-level

patterns. It may also be partially attributable to the sectoral composition of the regional economy. Retail, health services, and the public sector all have location quotients above one in El Paso (Orrenius 2016). Saunoris and Sheridan (2013) find evidence that favours the conservation hypothesis for the commercial and residential sectors in the United States overall, while the growth hypothesis is supported for the industrial sector in the short-run. The large service sector in El Paso may partially explain the lack of evidence for electricity-propelled growth in this region.

Obtaining evidence in favour of the neutrality hypothesis using data for El Paso is not completely surprising. That is because, similar to the rest of the United States and much of the global economy, El Paso is becoming more energy efficient. Over the course of the 40-year sample period employed for this study, the ratio of kilowatt-hours consumed to real personal income has declined substantially. In 1976, the value of that ratio is 0.385. By the end of the sample period in 2015, the value of that ratio declines to 0.247. As shown in Figure 1, that decline has been fairly steady and is not a consequence of possibly misleading short-term or temporary data developments. On the basis of these data and the results in Table 9, electric usage efficiency and metropolitan economic growth do not seem incompatible. In fact, the outcomes in Table 9 imply that policy attempts to encourage additional efficiency gains will not place economic expansion at risk in El Paso.

Beyond the electricity-growth results, Table 9 also sheds light on the roles of public and private

**Figure 1.** Electricity usage to real income ratio (kWh/Real Income, 2009 \$).

capital stock and employment variables in enhancing regional income performance. Shifts in the latter set of variables are found to precede changes in personal income. This is consistent with prior evidence compiled for this region. Fullerton, Gonzalez-Monzon, and Walke (2013) find that both public and private capital stocks, along with the size of the workforce, contribute to long-run growth in gross metropolitan product in El Paso. The results are also consistent with the finding of Lee, Chang, and Chen (2008) that the capital stock has a more pronounced impact on output than does energy utilization. Table 9 shows that private capital and public infrastructure, as well as human factors of production, are critical ingredients for regional economic development.

The results in Table 9 also help identify the causal factors affecting electricity consumption. In particular, changes in the capital stock are found to cause changes in metropolitan electricity usage. This is similar to the results of residential electricity demand studies that often consider the stock of electricity-using equipment as an important determinant of demand (Taylor 1975). Høltedahl and Joutz (2004) use urbanization as an indirect measure of the capital stock and find that it has a positive and significant effect on electricity consumption. The results in Table 9 reinforce the notion that the capital stock is a key determinant of electricity consumption.

Furthermore, while changes in income are not found to cause changes in electricity consumption, there is some evidence that total employment exerts a causal effect. The χ^2 statistic for the latter relationship surpasses the 10-percent critical value for the relevant distribution but not the 5-percent critical value. This is similar to the finding of Yu and Hwang (1984), in a national-level study for the United States, of unidirectional causality running from employment to energy consumption. Employment fluctuations reflect business cycle movements and changes in economic conditions which have been shown in a number of studies to impact electricity consumption (Espey and Espey 2004).

Figure 2 summarizes the relationships between variables implied by the Granger causality results reported in Table 9. Causal linkages that surpass the 5-percent significance threshold are designated by solid arrows while the linkage from employment

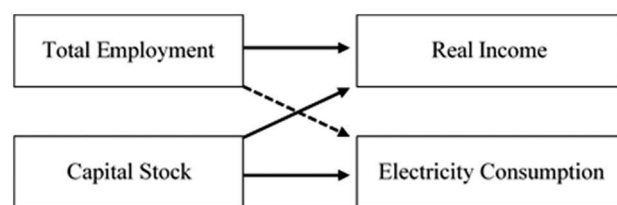


Figure 2. Implied causal linkages between variables.

to electricity consumption, which is only significant at the 10-percent level, is designated by a dashed arrow. The general implication of Figure 2 is that causality runs from the labour and capital factors of production to both real personal income and electricity consumption.

V. Conclusions

A large number of prior studies provide information about the relationship between electricity consumption and economic growth at the national-level. This effort contributes to the much smaller body of research on regional level interactions. It takes advantage of a dataset extending back forty years. The dataset is unique in that it incorporates an urban capital stock measure that synthesizes information on various types of public and private capital. Testing indicates that the logarithmically-transformed variables are I(1) and cointegrated. A vector error correction model is then developed and Granger causality tests are conducted to investigate which hypotheses regarding electricity-growth causality are upheld in the case of El Paso.

The results for this metropolitan economy, like several previous national-level studies for the United States as a whole, support the neutrality hypothesis. This hypothesis indicates that greater electricity consumption is not likely to boost economic growth and, conversely, that energy conservation efforts do not impose binding constraints on economic development. The local economy can absorb reductions in electricity consumption without sacrificing dynamism. The main policy implication of this finding is that regional authorities charged with the provision of electricity and the promotion of economic development, can confidently employ energy conservation strategies without fear of thwarting economic growth.

The evidence in support of the neutrality hypothesis contrasts with the finding of a previous electricity-growth study conducted at the metropolitan level for Guangzhou, China (He, Fullerton, and Walke 2017). That earlier study finds evidence in favour of the growth hypothesis. This contrast highlights the importance of examining electricity-growth relationships separately for different metropolitan areas and regions. Future research might usefully compare these results with those for urban economies in low-income countries or with multiple urban economies within a single country.

The results also have implications for the effects of capital stocks and labour inputs on regional income performance and electricity demand. The aggregate production function specified in Equation (1) posits that capital stocks, employment, and electricity utilization all figure into the aggregate production function. While the results do not support this claim in the case of electricity consumption, they do imply that changes in capital stocks and employment precede changes in local economic growth. This is consistent with prior evidence that public infrastructure, private capital stocks, and total employment contribute to local economic development. Evidence is also found for causality running from capital stocks and employment to electricity consumption. This aligns with the findings of previous research on electricity demand. Furthermore, the methodology used to develop the capital stock variable for this analysis could be applied in similar investigations of other urban and regional economies.

Finally, as mentioned in the introduction, many of the decisions affecting energy conservation and development strategies emanate from regional policymaking bodies. Thus, additional research on energy-growth relationships at the regional level has the potential to inform consequential local policy debates on these matters. Future research at the regional level could examine different types of energy usage as well as economic growth in particular segments of regional economies such as the industrial, commercial, and residential sectors.

Acknowledgments

Financial support for this research was provided by El Paso Water, City of El Paso Office of Management & Budget,

National Science Foundation Grant DRL-1740695, the UTEP Center for the Study of Western Hemispheric Trade, and the Hunt Institute for Global Competitiveness at UTEP. Econometric research assistance was provided by Patricia Arellano and Omar Solis.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the National Science Foundation [DRL-1740695]; El Paso Water; UTEP Hunt Institute for Global Competitiveness; City of El Paso Office of Management & Budget [13-1008-051 237563 MKB]; UTEP Center for the Study of Western Hemispheric Trade.

References

- Albala-Bertrand, J. M. 2010. "A Contribution to Estimate A Benchmark of Capital Stock. An Optimal Consistency Method." *International Review of Applied Economics* 24 (6): 715–729.
- Al-Shakarchi, M. R. G., and M. M. Ghulaim. 2000. "Short-Term Load Forecasting for Baghdad Electricity Region." *Electric Machines & Power Systems* 28 (4): 355–371.
- Altinay, G., and E. Karagol. 2005. "Electricity Consumption and Economic Growth: Evidence from Turkey." *Energy Economics* 27 (6): 849–856.
- Apergis, N., and J. E. Payne. 2012. "The Electricity Consumption-Growth Nexus: Renewable versus Non-Renewable Electricity in Central America." *Energy Sources, Part B: Economics, Planning, and Policy* 7 (4): 423–431.
- Bildirici, M. E., and F. Kayıkçı. 2012. "Economic Growth and Electricity Consumption in Former Soviet Republics." *Energy Economics* 34 (3): 747–753.
- Chen, S.-T., H.-I. Kuo, and -C.-C. Chen. 2007. "The Relationship between GDP and Electricity Consumption in 10 Asian Countries." *Energy Policy* 35 (4): 2611–2621.
- Cheng, Y. S., W. K. Wong, and C. K. Woo. 2013. "How Much Have Electricity Shortages Hampered China's GDP Growth?" *Energy Policy* 55: 369–373.
- Cheng-Lang, Y., H.-P. Lin, and C.-H. Chang. 2010. "Linear and Nonlinear Causality between Sectoral Electricity Consumption and Economic Growth: Evidence from Taiwan." *Energy Policy* 38 (11): 6570–6573.
- Chiou-Wei, S. Z., C. F. Chen, and Z. Zhu. 2008. "Economic Growth and Energy Consumption Revisited – Evidence from Linear and Nonlinear Granger Causality." *Energy Economics* 30 (6): 3063–3076.
- Ciarreta, A., and A. Zarraga. 2010. "Economic Growth - Electricity Consumption Causality in 12 European

- Countries: A Dynamic Panel Data Approach.” *Energy Policy* 38 (7): 3790–3796.
- Cowan, W. N., T. Chang, R. Inglesi-Lotz, and R. Gupta. 2014. “The Nexus of Electricity Consumption, Economic Growth and CO₂ Emissions in the BRICS Countries.” *Energy Policy* 66: 359–368.
- Enders, W. 2010. *Applied Econometric Time Series*. 3rd ed. Hoboken, NJ: John Wiley & Sons.
- EPEC. 1981. *1980 Annual Report*. El Paso, TX: El Paso Electric Company.
- EPEC. 2016. *2015 Annual Report*. El Paso, TX: El Paso Electric Company.
- Espey, J. A., and M. Espey. 2004. “Turning on the Lights: A Meta-Analysis of Residential Electricity Demand Elasticities.” *Journal of Agricultural and Applied Economics* 36 (1): 65–81.
- Fernandez, R. B. 1981. “A Methodological Note on the Estimation of Time Series.” *Review of Economics and Statistics* 63 (3): 471–476.
- Friedman, M. 1962. “The Interpolation of Time Series by Related Series.” *Journal of the American Statistical Association* 57 (300): 729–757.
- Fullerton, T. M., Jr., A. Gonzalez-Monzon, and A. G. Walke. 2013. “Physical Infrastructure and Economic Growth in El Paso.” *Economic Development Quarterly* 27 (4): 363–373.
- Fullerton, T. M., Jr., D. R. Macias, and A. G. Walke. 2016. “Residential Electricity Demand in El Paso.” *Journal of Regional Analysis & Policy* 46 (2): 154–167.
- Ghali, K. H., and M. I. T. El-Sakka. 2004. “Energy Use and Output Growth in Canada: A Multivariate Cointegration Analysis.” *Energy Economics* 26 (2): 225–238.
- Ghosh, S. 2002. “Electricity Consumption and Economic Growth in India.” *Energy Policy* 30 (2): 125–129.
- Gill, G. S., and R. D. Ellison. 1976. “Regional Demand for Electricity and Implications for Policy.” *Annals of Regional Science* 10 (2): 9–23.
- Gregory, A. W., and B. E. Hansen. 1996. “Residual-Based Tests for Cointegration in Models with Regime Shifts.” *Journal of Econometrics* 70 (1): 99–126.
- Halicioglu, F. 2007. “Residential Electricity Demand Dynamics in Turkey.” *Energy Economics* 29 (2): 199–210.
- Hamdi, H., R. Sbia, and M. Shahbaz. 2014. “The Nexus between Electricity Consumption and Economic Growth in Bahrain.” *Economic Modelling* 38 (2): 227–237.
- He, Y., T. M. Fullerton Jr., and A. G. Walke. 2017. “Electricity Consumption and Metropolitan Economic Performance in Guangzhou: 1950–2013.” *Energy Economics* 63: 154–160.
- Holtedahl, P., and F. L. Joutz. 2004. “Residential Electricity Demand in Taiwan.” *Energy Economics* 26 (2): 201–224.
- Huang, B., M. J. Hwang, and C. W. Yang. 2008. “Causal Relationship between Energy Consumption and GDP Growth Revisited: A Dynamic Panel Data Approach.” *Ecological Economics* 67 (1): 41–54.
- Iyke, B. N. 2015. “Electricity Consumption and Economic Growth in Nigeria: A Revisit of the Energy-Growth Debate.” *Energy Economics* 51: 166–176.
- Izquierdo, M., A. Moreno-Rodríguez, A. González-Gil, and N. García-Hernando. 2011. “Air Conditioning in the Region of Madrid, Spain: An Approach to Electricity Consumption, Economics, and CO₂ Emissions.” *Energy* 36 (3): 1630–1639.
- Jamil, F., and E. Ahmad. 2010. “The Relationship between Electricity Consumption, Electricity Prices and GDP in Pakistan.” *Energy Policy* 38 (10): 6016–6025.
- Johansen, S. 1991. “Estimation and Hypothesis Testing of Cointegration Vectors in Gaussian Vector Autoregressive Models.” *Econometrica* 59 (6): 1551–1580.
- Johansen, S. 1995. *Likelihood-Based Inference in Cointegrated Vector Autoregressive Models*. Oxford, UK: Oxford University Press.
- Jumbe, C. B. L. 2004. “Cointegration and Causality between Electricity Consumption and GDP: Empirical Evidence from Malawi.” *Energy Economics* 26 (1): 61–68.
- Kalimeris, P., C. Richardson, and K. Bithas. 2014. “A Meta-Analysis Investigation of the Direction of the Energy-GDP Causal Relationship: Implications for the Growth-Degrowth Dialogue.” *Journal of Cleaner Production* 67: 1–13.
- Karanfil, F., and Y. Li. 2015. “Electricity Consumption and Economic Growth: Exploring Panel-Specific Differences.” *Energy Policy* 82: 264–277.
- Klein, L. R. 1969. “The Specification of Regional Econometric Models.” *Papers In Regional Science* 23: 105–115.
- Kwiatkowski, D., P. C. B. Phillips, P. Schmidt, and Y. Shin. 1992. “Testing the Null Hypothesis of Stationarity against the Alternative of a Unit Root: How Sure are We that Economic Time Series Have a Unit Root?” *Journal of Econometrics* 54 (1–3): 159–178.
- Lee, C. C., C. P. Chang, and P. F. Chen. 2008. “Energy-Income Causality in OECD Countries Revisited: The Key Role of the Capital Stock.” *Energy Economics* 30 (5): 2359–2373.
- Lütkepohl, H., and M. Krätzig. 2004. *Applied Time Series Econometrics*. Cambridge, UK: Cambridge University Press.
- Mozumder, P., and A. Marathe. 2007. “Causality Relationship between Electricity Consumption and GDP in Bangladesh.” *Energy Policy* 35 (1): 395–402.
- Narayan, P. K., and A. Prasad. 2008. “Electricity Consumption–Real GDP Causality Nexus: Evidence from a Bootstrapped Causality Test for 30 OECD Countries.” *Energy Policy* 36 (2): 910–918.
- Narayan, P. K., and R. Smyth. 2005. “Electricity Consumption, Employment and Real Income in Australia Evidence from Multivariate Granger Causality Tests.” *Energy Policy* 33 (9): 1109–1116.
- Omri, A. 2014. “An International Literature Survey on Energy-Economic Growth Nexus: Evidence from Country-Specific Studies.” *Renewable and Sustainable Energy Reviews* 38: 951–959.
- Orrenius, P. M. 2016. *At the Heart of Texas: Cities’ Industry Clusters Drive Growth*. Dallas, TX: Federal Reserve Bank of Dallas.
- Ouédraogo, I. M. 2010. “Electricity Consumption and Economic Growth in Burkina Faso: A Cointegration Analysis.” *Energy Economics* 32 (3): 524–531.

- Ozturk, I. 2010. "A Literature Survey on Energy-Growth Nexus." *Energy Policy* 38 (1): 340–349.
- Ozturk, I., and A. Acaravci. 2011. "Electricity Consumption and Real GDP Causality Nexus: Evidence from ARDL Bounds Testing Approach for 11 MENA Countries." *Applied Energy* 88 (8): 2885–2892.
- Pao, H.-T. 2009. "Forecast of Electricity Consumption and Economic Growth in Taiwan by State Space Modeling." *Energy* 34 (11): 1779–1791.
- Payne, J. E. 2009. "On the Dynamics of Energy Consumption and Output in the US." *Applied Energy* 86 (4): 575–577.
- Perron, P. 1989. "The Great Ccrash, the Oil Price Shock, and the Unit Root Hypothesis." *Econometrica* 57 (6): 1361–1401.
- Saunoris, J. W., and B. J. Sheridan. 2013. "The Dynamics of Sectoral Electricity Demand for a Panel of US States: New Evidence on the Consumption Growth Nexus." *Energy Policy* 61: 327–336.
- Shahbaz, M., and M. Feridun. 2012. "Electricity Consumption and Economic Growth Empirical Evidence from Pakistan." *Quality and Quantity* 46 (5): 1583–1599.
- Shahbaz, M., M. Zeshan, and T. Afza. 2012. "Is Energy Consumption Effective to Spur Economic Growth in Pakistan? New Evidence from Bounds Test to Llevel Relationships and Granger Causality Tests." *Economic Modelling* 29 (6): 2310–2319.
- Solarin, S. A., and M. Shahbaz. 2013. "Trivariate Causality between Economic Growth, Urbanization and Electricity Consumption in Angola: Cointegration and Causality Analysis." *Energy Policy* 60: 876–884.
- Stern, D. I. 2000. "A Multivariate Cointegration Analysis of the Role of Energy in the US Macroeconomy." *Energy Economics* 22 (2): 267–283.
- Tang, C. F., and E. C. Tan. 2013. "Exploring the Nexus of Electricity Consumption, Economic Growth, Energy Prices and Technology Innovation in Malaysia." *Applied Energy* 104: 297–305.
- Tang, C. F., M. Shahbaz, and M. Arouri. 2013. "Re-Investigating the Electricity Consumption and Economic Growth Nexus in Portugal." *Energy Policy* 62: 1515–1524.
- Taylor, L. D. 1975. "The Demand for Electricity: A Survey." *Bell Journal of Economics* 6 (1): 74–110.
- USDC. 2003. *Fixed Asset and Consumer Durable Goods in the United States, 1925-97*. Washington, DC: United States Department of Commerce.
- Wangpattarapong, K., S. Maneewan, N. Ketjoy, and W. Rakwichian. 2008. "The Impacts of Climatic and Economic Factors on Residential Electricity Consumption of Bangkok Metropolis." *Energy and Buildings* 40 (8): 1419–1425.
- Wolde-Rufael, Y. 2014. "Electricity Consumption and Economic Growth in Transition Countries: A Revisit Using Bootstrap Panel Granger Causality Analysis." *Energy Economics* 44 (7): 325–330.
- Yoo, S.-H. 2005. "Electricity Consumption and Economic Growth: Evidence from Korea." *Energy Policy* 33 (12): 1627–1632.
- Yu, E. S. H., and B. K. Hwang. 1984. "The Relationship between Energy and GNP: Further Results." *Energy Economics* 6 (3): 186–190.
- Yu, E. S. H., and J. C. Jin. 1992. "Cointegration Tests of Energy Consumption, Income, and Employment." *Resources and Energy* 14 (3): 259–266.
- Yuan, J., C. Zhao, S. Yu, and Z. Hu. 2007. "Electricity Consumption and Economic Growth in China: Cointegration and Co-Feature Analysis." *Energy Economics* 29 (6): 1179–1191.