Journal of Economic Theory and Econometrics, Vol. 31, No. 4, Dec. 2020, 69–85

Estimation of Residential Electricity Demand in Korea Allowing for a Structural Break*

Seong Yeon Chang†

Abstract This study examines the time series characteristics of residential electricity demand and its determinants in Korea and the short-run and long-run relationship among them. We employ unit root tests, cointegration, and error-correction models on annual time series for the period 1972–2019. The rapid development of Korea over this period provides clear evidence of the possibility of structural breaks. We find that residential electricity demand and its determinants are trend-stationary processes with a slope change, which implies that there is no need to invoke cointegration methods under the unit root assumption. We expect that the essential modeling strategy presented in this article will be widely applicable.

Keywords Cointegration, Korea, Price Elasticity, Residential Electricity Demand, Structural Breaks, Unit Root

JEL Classification C22, C51, D12

*I am very grateful to the editor, Noh-Sun Kwark, the co-editor, Jin Seo Cho and two anonymous referees for valuable comments and suggestions.

†Department of Economics, Soongsil University, 369, Sangdo-ro, Dongjak-gu, Seoul, Korea. E-mail: sychang@ssu.ac.kr

Received November 11, 2020, Revised December 14, 2020, Accepted December 17, 2020

1. INTRODUCTION

Electricity demand is of vital importance for energy producers and policymakers. Electricity markets are distinguishable from other markets because electricity cannot be stored in substantial quantities under current battery technology, its generation capacity is limited, and the retail markets are tightly regulated. Elasticities of demand are crucial to determine the welfare implications of price and income changes. Many empirical studies address the estimation of electricity demand functions for this purpose.

The conventional methodology for estimating electricity demand is the cointegration regression and error-correction models (see, e.g., Engle and Granger, 1987; Johansen, 1988). A unit root is a well-known example of a nonstationary process. Testing for a unit root against stationarity has been an important research topic from both theoretical and empirical perspectives. In energy literature, it is widely known that the electricity demand and unit price of electricity follow unit root processes. Hence, the cointegration regression and error-correction model is a commonly accepted procedure to estimate the short-run and long-run elasticities of electricity demand. Important early contributions to modeling in electricity markets include Engle *et al.* (1989), Bentzen and Engsted (1993), Silk and Joutz (1997), and Bennstock *et al.* (1999) to name a few. There have been some studies about the estimation of electricity demand function in Korea employing the cointegration regression and error-correction models. Lee and Heo (1998) analyze price and income elasticities of electricity demand to clarify its long-run and short-run structure. Park *et al.* (2011) apply a time-varying coefficient cointegration method to provide an empirical analysis of long-run electricity demand forecast for Korea. Lim *et al.* (2014) estimate price and income elasticities in Korean service sector. Parameter instability has not been introduced explicitly by this class of models. The literature on parameter instability and especially structural breaks has developed. See for example, the studies of Hughes *et al.* (2008) for the gasoline market, Miller and Ratti (2009) for effects of oil prices on stock markets, and Blanchard and Gali (2010) for effects of oil prices on the economy. Recently, Chang *et al.* (2014) propose a smooth time-varying coefficient (TVC) cointegration approach to modeling electricity demand. The TVC model allows income and outcome elasticities to vary over time.

This study reexamines the time series characteristics of the variables in residential electricity demand function. Perron (1989) shows that the Dickey and Fuller (1979) type unit root test is biased in favor of non-rejection of the unit root null hypothesis when the process is trend stationary with a slope change.

Recent advances in testing for and estimating a structural break in a trend function have made possible the development of unit root tests that allow for a change in trend under both the null and alternative hypotheses. Kim and Perron (2009) propose unit root testing procedures that allow for a structural change under both the null and alternative hypotheses; see also, Carrion-i Silvestre *et al.* (2009) for an extension to the case with multiple changes and Chang and Perron (2017) for fractionally integrated errors. In this study, we consider the possibility that the residential electricity demand and its determinants have experienced structural breaks, thereby estimating residential electricity demand functions. Interestingly, Pourazarm and Cooray (2013) consider the possibility of structural changes in Iranian residential electricity demands to test for the null hypothesis of having an autoregressive unit root. They use the testing procedure of Narayan and Popp (2010) under the assumption that electricity demands in Iran have experienced two structural changes and suggest the autoregressive distributed lag model to estimate the long-run equilibrium and short-run dynamics.

We investigate the time series properties of crucial variables, such as the residential electricity sales, unit prices, number of households, and Gross National Income (GNI) in residential electricity demand functions. Especially, electricity usage is subject to structural changes due to the revolution in computing and portable devices and the proliferation of electricity usage in heating and cooling. These changes might be common across all market sectors and in countries less dynamic than Korea. Notably, Korea has developed over the past few decades. Table 1 below exhibits the rapid increases in industrial production (IP), Gross Domestic Production (GDP), and residential electricity sales since 1985. Thus, we can consider Korea as one of the most compelling cases for a model that allows structural changes. Furthermore, electricity supply in Korea is stable and predictable because the Korean electricity market has virtually no imports or exports of electricity and is controlled by a near monopolistic distributor, the Korea Electric Power Corporation (KEPCO).

We focus on the residential electricity demand in other sectors. Although the proportion of residential electricity demand is around 12–15% of the total electricity demand in Korea, it effectively captures the possibility of structural breaks, in that the tariff system of residential electricity demand and the size and age structure of family households have dramatically changed. Therefore, an investigation of the behavior of residential end users is essential for policymakers to establish energy policies. More recently, Hong and Kim (2018) estimate the price elasticity of the peak electricity demand of the residential sector in Korea using high frequency data and find that the price elasticity depends on temper-

Table 1: Summary statistics for selected years

	Annual Sales	Price Index (2015 = 100)			Annual GDP	IP
Year	(GWh)	Residential	CPI	PPI	(Billion KRW)	
1985	9,632	73	31	52	88,130	11
1995	28,303	86	55	65	436,989	31
2005	50,873	111	78	86	957,448	66
2015	63,794	124	100	100	1,658,020	100
2019	70,455	107	105	105	1,919,040	108

Note: Price indices and industrial production (IP) are the annual average.

ature. Kim *et al.* (2019) present the impact of the population age structure on residential electricity demand.

The rest of this article is structured as follows: Section 2 investigates time series properties of economic variables in the residential electricity demand function. Section 3 presents the main empirical results and provides a comparison with the conventional cointegration and error-correction models. Section 4 offers a brief conclusion.

2. UNIVARIATE ANALYSIS OF THE TIME-SERIES PROPERTIES

The time series properties of the residential electricity sales, real unit prices, number of households, and GNI are analyzed. The dataset spans the period 1972–2019. The series are presented in Figure 1. Below, we show strong evidence for trend-stationarity when using unit root tests that allow for a break in the trend function (Kim and Perron, 2009; Perron, 1989, 1997).

The standard Augmented Dickey-Fuller unit root test (ADF) (Dickey and Fuller, 1979; Said and Dickey, 1984) applied to the time series of interest seems to provide strong evidence for a unit root; see Table 2. The null hypothesis of a unit root cannot be rejected for all variables considered. Other recent unit root tests proposed by Ng and Perron (2001) also show the same results. Furthermore, the stationarity test of Kwiatkowski *et al.* (1992) (KPSS) reverses the null and alternative hypotheses and rejects the null hypothesis of level and trend stationarity for lag truncation parameters $l = 1, 4$. Therefore, the combined results from both ADF and KPSS tests suggest that all the series turn out to be unit root processes, that is, $I(1)$ processes.

Figure 1 suggests the presence of structural breaks in the slopes of the trends

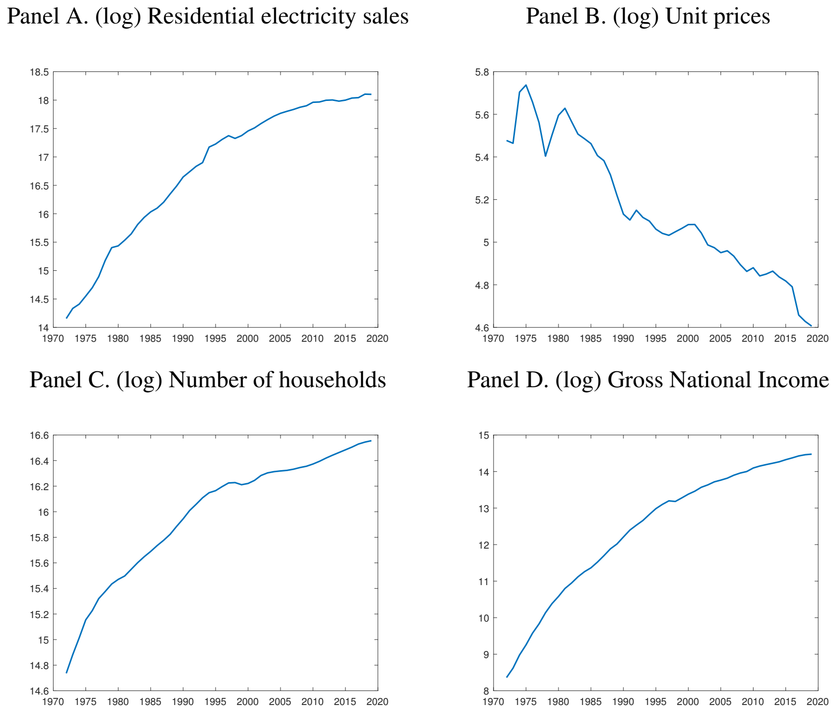

Figure 1: Time series of residential electricity sales and its determinants

of all the series considered. As suggested in Perron (1989), the unit root test results in Table 2 could be misleading. To test for the existence of these breaks, we use the testing procedure of Perron and Yabu (2009), which is valid regardless of the noise component being stationary or having an autoregressive unit root, and thus, circumvents the problem of pretesting for a unit root usually required to apply structural break tests. The results in Table 3 show that the stability of the slope parameter of the trend function for all the series, except the unit price, can be rejected at the 1% significance level, providing strong arguments for the need of unit root tests that allow for a one-time break in the trend function. For the unit price, the stability of the slope parameter of the trend function can be rejected at the 10% significance level.

Perron (1989) establishes unit root tests in the presence of structural breaks in the trend. Succeeding studies extended his original tests to the case of an unknown break date; Perron (1997), Zivot and Andrews (1992), Perron and Rodríguez (2003), and the reference therein. Notably, these tests allow the pos-

Table 2: Tests of unit roots hypothesis

	ADF	KPSS	
		$l = 1$	$l = 4$
Electricity sales	0.019 (7)	0.597***	0.271***
Unit price	-2.585 (2)	0.148*	0.101
Number of households	-2.307 (1)	0.564***	0.267***
GNI	-1.602 (7)	0.581***	0.269***

Note: The relevant test is derived from the OLS estimation of the following autoregression for the variable involved:

$$\Delta x_t = \delta_0 + \delta_1 (\text{Time})_t - \delta_2 x_{t-1} + \sum_{i=1}^{k} \phi_i \Delta_{t-i} + u_t, \tag{1}$$

where ADF is the t-statistics for testing the significance of δ_2 when a time trend is included in Eq. (1). The calculated statistics are those reported in Dickey and Fuller (1981). The critical values at 5% and 1% for $T = 48$ are -3.51 and -4.14. The lag length structure of ϕ_i of the dependent variable is determined using a recursive procedure in the light of a Lagrange multiplier (LM) autocorrelation test (for orders up to 13) that is asymptotically distributed as chi-squared distribution and the value of t-statistic of the coefficient associated with the last lag in the estimate autoregression. The KPSS statistics are for testing the null hypothesis that the series are $I(0)$ when the residuals are computed from a regression equation with intercept and time trend. The KPSS statistics test for lag-truncation parameters one and four ($l = 1$ and $l = 4$) because it is unknown how many lagged residuals should be used to construct a consistent estimator of the residual variance. The critical values are 0.119, 0.146 and 0.216 at the 10%, 5% and 1% significance level, respectively. ***, **, * indicate statistical significance at the 1%, 5%, 10% level, respectively.

Table 3: Perron and Yabu (2009) tests for structural changes in the trend function for time series with a stationary or integrated noise component

Series	Exp-Wald statistic
Electricity sales	25.319***
Unit price	1.548*
Number of households	20.164***
GNI	8.826***

Note: The critical values at 10%, 5%, and 1% are 1.40, 1.93, 3.27. *, **, *** indicate statistical significance at the 10%, 5%, 1% level, respectively.

sibility of a break only under the alternative hypothesis (stationary noise component) and not under the null hypothesis (integrated noise component). It is well known that the Zivot and Andrews (1992) test and some of the tests proposed in Perron (1997) tend to falsely reject the null hypothesis of a unit root if there exists a large break in the slope of the trend function, and a unit root noise component is actually present (see Vogelsang and Perron, 1998; Kim and Perron, 2009). To avoid this problem, Kim and Perron (2009) propose unit root testing procedures that allow for a structural change under both the null and alternative hypotheses and that include a pretest for the existence of a break using the Perron and Yabu (2009) test. If this pre-test rejects the null of no break, the limit distribution of the unit root test is identical to the case of the known break date (see, e.g., Perron, 1989; Perron and Vogelsang, 1993). This is useful in practice because the test has much greater power when a break exists.

We apply the Kim and Perron (2009) and the version of the Perron (1997) tests based on selecting the break date by minimizing the t-statistic of the change in slope, which is free from the size distortion alluded to above. We assume the "changing growth" model for residential electricity sales. As shown in Table 4, the results provide clear evidence for trend-stationarity if a break in the slope of the trend function is allowed. The null hypothesis of a unit root is rejected at the 1% and 2.5% significance levels with the Perron (1997) test, $t_{\hat{\alpha}}$, and the Kim and Perron (2009) test, $t_{\alpha}(\hat{\lambda}_{tr}^{AO})$, respectively, in favor of a trend-stationary process with a single change in the rate of growth. The change occurred in 1995 and consisted in abrupt decrease in the rate of residential electricity sales.

Furthermore, we assume the "changing growth" model for the remaining three variables. For the unit prices, the null of a unit root is rejected at the 1% significance level with $t_{\alpha}(\hat{\lambda}_{tr}^{AO})$, but not with $t_{\hat{\alpha}}$. For the number of households, the null of a unit root is rejected at the 1% significance level with $t_{\hat{\alpha}}$, but not with $t_{\alpha}(\hat{\lambda}_{tr}^{AO})$. For the GNI, the null hypothesis of a unit root is rejected at the 1% and 5% significance levels with $t_{\hat{\alpha}}$ and $t_{\alpha}(\hat{\lambda}_{tr}^{AO})$, respectively. The results show that the data does not support the common assumption of variables in the residential electricity demand estimation being integrated processes. This finding has important implications for the multivariate modeling of residential electricity sales and its determinants. The results indicate that there are no differences in the order of integration of these variables, which can be better described as trend-stationary processes. Therefore, the existence of long-term relationships can be tested using standard regression models while cointegration methods that require the assumption of unit root processes in residential electricity sales and its determinants in the electricity demand estimation can be avoided.

Once we establish that residential electricity sales and its determinants are better characterized as trend-stationary processes, we apply the nonparametric

Table 4: Tests for a unit root with a one-time break in the trend function

	Electricity sales	Unit price	Number of households	GNI
T_b	1995	1994	1992	1992
k	7	1	1	1
$\hat{\mu}$	14.435	5.581	15.067	9.130
$t_{\hat{\mu}}$	120.23^a	192.63^a	261.01^a	49.876^a
$\hat{\beta}$	0.113	-0.007	0.045	0.159
$t_{\hat{\beta}}$	13.23^a	-2.11^c	9.45^a	10.57^a
$\hat{\gamma}$	-0.023	-0.012	-0.009	-0.030
$t_{\hat{\gamma}}$	-3.73^a	-4.60^a	-2.65^d	-2.61
$\hat{\alpha}$	0.97	0.34	0.93	0.95
$t_{\hat{\alpha}}$	18.07^a	3.32	21.06^a	23.51^a
$S(\hat{e})$	0.095	0.005	0.021	0.211
$t_\alpha(\hat{\lambda}_{tr}^{AO})$	-4.435^b	-5.995^a	-3.548	-3.775^c

Note: The regression model for the unit root tests is specified by the following equations: (i) $y_t = \mu + \beta t + \gamma DT_t^* + \tilde{y}_t$, where $DT_t^* = 1(t > T_b)(t - T_b)$ and (ii) $\tilde{y}_t = \alpha \tilde{y}_{t-1} + \sum_{i=1}^{k} c_i \Delta \tilde{y}_{t-1} + e_t$. The symbols used are defined as follows: T_b is the estimated break date; k is the number of lagged differences added to correct for serial correlation; $S(\hat{e})$ is the standard error of the regression; $\hat{u}$, $\hat{\beta}$, $\hat{\gamma}$ are the regression coefficients of the trend function and $t_{\hat{\mu}}, t_{\hat{\beta}}, t_{\hat{\gamma}}$ the corresponding t-statistic values. $\hat{\alpha}$ is the sum of the autoregressive coefficients and $t_{\hat{\alpha}}$ is the Perron (1997) unit root test statistic. $t_\alpha(\lambda_{tr}^{AO})$ is the Kim and Perron (2009) unit root test. *a, b, c, d* indicate statistical significance at the 1%, 2.5%, 5% and 10% level, respectively (critical values from Perron, 1997, for the test $t_{\hat{\alpha}}$, and from Perron and Vogelsang, 1993, Table 1, for the test $t_\alpha(\lambda_{tr}^{AO})$).

nonlinear co-trending analysis proposed by Bierens (2000) to investigate the existence of a common nonlinear deterministic trend among them. Nonlinear co-trending is a special case of common features in which one or more linear combinations (called co-trending vectors) of nonstationary time series are stationary about a linear trend or a constant, indicating that the series share common nonlinear deterministic time trends. Table 5 shows the results of applying the Bierens test to residential electricity sales and its determinants. The results indicate the existence of three co-trending vectors among residential electricity sales and its determinants and therefore strongly suggest the existence of one common nonlinear deterministic trend.

Note that the estimates of the break dates are similar for all the time series considered in this study: 1995, 1994, 1992, and 1992 for the residential electricity sales, unit prices, number of households, and GNI, respectively. Applying

Table 5: Nonparametric nonlinear co-trending test for residential electricity sales and its determinants

r		10% critical region	5% critical region
1	0.06319	> 0.35183	> 0.46577
2	0.10718	> 0.53561	> 0.67420
3	0.27879	> 0.70366	> 0.86038
4	1.06179**	> 0.86182	> 1.03454

Note: The null hypothesis is that there are r co-trending vectors against the alternative of $r-1$ co-trending vectors. The existence r co-trending vectors in $r+1$ series indicates the presence of r linear combinations of the series that are stationary around a linear trend and that these series share a single common nonlinear deterministic trend. ** indicates statistical significance at the 5% level. The results have been obtained with EasyReg International by Herman Bierens, referenced as Bierens (2015).

the methodology of Perron and Zhu (2005), we show that when constructing a 95% confidence interval, one cannot consider the estimates of the break dates to be statistically different (Table 6).

Table 6: Break date estimates and 95% confidence intervals (CIs)

	Break Date	CI
Electricity sales	1995	(1993, 1997)
Unit price	1994	(1992, 1996)
Number of households	1992	(1989, 1995)
GNI	1992	(1990, 1994)

According to these estimates, there has been a large decrease in the rate of growth of observed residential electricity sales since the mid-1990s. The post-break rate has reduced by -0.023. For the unit prices, the rate of growth has declined further after the break date. There has been a decrease in the rate of growth in the number of households since 1992. These figures are consistent with the significant reduction in the total fertility rate in Korea since the 1990s. The next section discusses how this abrupt decrease in the growth rate of residential electricity demand might indicate a decline in the growth rate of the observed number of households. In summary, residential electricity sales can be better described as a trend-stationary process with a one-time permanent shock that cannot be interpreted as part of the natural variability.

3. TIME SERIES MODELS FOR RESIDENTIAL ELECTRICITY DEMAND

This section presents statistically adequate models for residential electricity sales. We show that parsimonious time series models can provide a very good fit for observed residential electricity sales and produce basic estimates of elasticities within the ranges reported in the literature, using different methods. We have presented evidence that residential electricity sales and its determinants follow nonlinear deterministic trends, which implies that the variables tend to stay together in their nonlinear movement. In contrast to a cointegration model, the long-run movements are governed by nonlinear deterministic paths and shocks have temporary effects. The following regression represents the general form of the models:

$$S_t = \beta_0 + \beta_1 P_t + \beta_2 HH_t + \beta_3 GNI_t + \sum_{j=1}^{J} \phi_j S_{t-j} + u_t \tag{2}$$

where S_t is residential electricity sales. As covariates, we use the unit price of residential electricity (P_t), number of households (HH_t), and Gross National Income (GNI_t). Notably, we use Hansen's (2000) method based on a "fixed regressor bootstrap" to estimate the break date in (2) and split the whole sample into two subsamples.[1] We choose the number of lags based on the statistical significance of the parameters and to obtain nearly-normal residuals with no autocorrelations or heteroskedasticity and a functional form deemed well specified with stable parameters.

Table 7 shows the estimated coefficients of the proposed model for residential electricity sales in Korea. Although the results of the misspecification testing are not shown here, the model is statistically adequate, in that the residuals do not show autocorrelation, they are homoskedastic, normal, and the estimated parameters are stable. Notably, all the coefficients have shown signs expected from the literature on electricity demand estimation, as follows: (i) the price elasticity β_1 is estimated to be significantly negative in the pre-break sample, while it is insignificant in the post-break sample; (ii) the income elasticity β_3 is estimated to be positive in the pre- and post-break samples; (iii) the impact of the number of households is estimated to be significantly negative after the break point,

[1] We use the MATLAB codes from Bruce Hansen's website.

Table 7: Estimated coefficients and coefficient of determination of regression (2)

	β_0	β_1	β_2	β_3	ϕ_1	R^2	$S(\hat{u})$
1972-1995	17.807***	-0.523***	-0.481	0.755***	-	0.998	0.003
	(4.987)	(-6.330)	(-1.665)	(8.757)			
1996-2019	19.472***	-0.128	-0.963***	0.552***	0.396***	0.994	0.000
	(3.754)	(-1.015)	(-3.385)	(4.731)	(3.061)		

Note: Figures in parentheses show the t-statistic values. *** indicates statistical significance at the 1% level.

which is compelling because the Korean fertility rate has declined dramatically and household sizes are also reducing.

In preceding research, residential electricity sales and its determinants are usually assumed to be integrated processes without breaks, and accordingly an error-correction model (ECM) based on a cointegrating relation is considered. Their long-run relationship is then investigated, applying the ordinary least squares (OLS) method on the simple regression model, in which the regressor x_t is assumed to be a one-dimensional vector for ease of exposition:

$$y_t = \beta x_t + u_t. \tag{3}$$

The series $\{x_t\}$ and $\{y_t\}$ are said to be cointegrated if there exists a linear combination of those nonstationary series that is stationary. Under the assumption of having a cointegrating relationship among the variables, the estimate of β in (3) reports a measure of the long-run effect of x_t on y_t. For instance, the long-run estimate of the price elasticity can be calculated using the estimated coefficient of the unit price in this equation. In addition, the residuals $\hat{u}_t$ can be used as an error-correction term in the ECM, as follows:

$$\Delta y_t = \mu + \alpha \Delta x_t - (1-\gamma)\hat{u}_{t-1} + \varepsilon_t$$

from which the estimates of α and (1-γ) would represent the short-run effect and the speed of adjustment toward the long-run effect, respectively. To check for a long-run equilibrium relationship among the variables in the residential electricity demand function, we consider the conventional cointegration regression model:

$$S_t = \alpha_0 + \alpha_1 P_t + \alpha_2 HH_t + \alpha_3 GNI_t + u_t \tag{4}$$

so that u_t is stationary. We obtain efficient estimates of the parameters using Dynamic Ordinary Least Squares (DOLS) with one lag and lead terms (Saikkonen,

Table 8: Estimates of the cointegration relationship between electricity sales and its determinants using the DOLS estimates with one lag and lead terms

α_0	α_1	α_2	α_3
2.355	-0.089**	-0.084	0.063
(1.031)	(-2.037)	(-0.581)	(0.810)

Note: Figures in parentheses show the t-statistic values. ** indicates statistical significance at the 5% level. The standard errors were estimated using the Newey-West heteroskedasticity-robust procedure.

1991; Stock and Watson, 1993). Table 8 reports the estimated OLS coefficients and t-statistics in (4). They show that many estimates are not statistically significant. With the exception of the contemporary value of the unit price (P_t), all other series included to account for residential electricity demand are not statistically significant. A comparison of the estimates of regression parameters in (2) and (4) emphasizes again the need to identify the source of nonstationarity in the variables.

The estimates $(\hat{\alpha}_0, \hat{\alpha}_1, \hat{\alpha}_2, \hat{\alpha}_3)$ can then be used to estimate the following error-correction model using the OLS method:

$$\begin{aligned}\Delta S_t = \mu + \rho(S_{t-1} - \hat{\alpha}_0 - \hat{\alpha}_1 P_{t-1} - \hat{\alpha}_2 HH_{t-1} - \hat{\alpha}_3 GNI_{t-1}) \\ + \sum_{i=0}^{j} \phi_i \Delta P_{t-i} + \sum_{i=0}^{l} \psi_i \Delta HH_{t-i} + \sum_{i=0}^{m} \zeta_i \Delta GNI_{t-i} + \varepsilon_t. \end{aligned} \tag{5}$$

Table 9 presents the parameter estimates of the ECM (5). The results show that many estimates are not statistically significant. With the exception of ΔP_t, ΔHH_t, and ΔHH_{t-1}, all other series included to account for variability in residential electricity sales are not statistically significant. This could be considered as a sign of poor model specification. In particular, the coefficients on the lagged values of ΔP_t and ΔGNI_t are not statistically significant. Moreover, the coefficient ρ that measures the speed of adjustment toward the long-run effect is not statistically significant either. These give additional support to our results in Section 2 that the unit price and the GNI do not contribute to the short-run dynamics of electricity sales and that there are no significant short-term feedback processes, at least when considering an annual frequency.

Table 9: Estimates of the error-correction model (5)

μ	ρ	ϕ_0	ϕ_1	ψ_0	ψ_1	ζ_0	ζ_1
0.092	-0.006	-0.594***	-0.462	0.756***	0.308***	0.644	-0.152
(0.307)	(-0.366)	(-4.787)	(-1.151)	(3.003)	(3.055)	(1.561)	(-0.854)

Note: Figures in parentheses show the t-statistic values. *** indicates statistical significance at the 1% level.

4. CONCLUDING REMARKS

This article demonstrates the importance of estimating residential electricity demand functions accurately to inform policymakers and distributors such as KEPCO, and suggests improved econometric models for this purpose. Our approach to residential electricity demand allows us to model structural breaks in the relevant variables. Further, we show that the cointegration regression and error-correction models do not allow for structural breaks satisfactorily; the null of a unit root cannot be rejected when the process of interest is trend-stationary with a slope change.

Our main empirical findings reveal interesting features. For example, the price elasticity is -0.523 before the break, while it is not statistically significant, that is, inelastic after the break. Similarly, the impacts of the number of households are also dramatically different before and after the break. Because the size of family households reduces and their consumed electricity volumes are relatively small, the addition of the number of households has a negative impact on the total consumed volume of residential electricity demand after the break point. Finally, we find that the demand for residential electricity is income elastic, clearly due to the tariff system in Korea; however, it becomes less elastic after the break point. The relative price of residential electricity is reducing faster than the real prices of other services, due to government price regulation and cost efficient nuclear power generators. This makes consumers less sensitive to price changes. An extension to electricity demand in the commercial and industrial sectors is the objective of an ongoing project.

REFERENCES

Bennstock, M., Goldin, E., and D. Nabot (1999). "The Demand for Electricity in Israel," *Energy Economics* 21, 168–183.

Bentzen, J. and T. Engsted (1993). "Short- and Long-Run Elasticities in Energy Demand: A Cointegration Approach," *Energy Economics* 15, 9–16.

Bierens, H. J. (2000). "Nonparametric Nonlinear Cotrending Analysis, with an Application to Interest and Inflation in the United States," *Journal of Business & Economic Statistics* 18, 323–337.

Bierens, H. J. (2015). *EasyReg International*, Department of Economics, Pennsylvania State University, University Park, PA (http://www.personal.psu.edu/hxb11/EASYREG.HTM).

Blanchard, O. J. and J. Gali (2010). "The Macroeconomic Effects of Oil Price Shocks: Why are the 2000s So Different from the 1970s?," in *International Dimensions of Monetary Policy*, eds., J. Gali and M. Gettler, University of Chicago Press, Chicago, 373–421.

Carrion-i Silvestre, J. L., Kim, D., and P. Perron (2009). "GLS-Based Unit Root Tests with Multiple Structural Breaks under Both the Null and the Alternative Hypotheses," *Econometric Theory* 25, 1754–1792.

Chang, S. Y. and P. Perron (2017). "Fractional Unit Root Tests Allowing for a Structural Change under Both the Null and Alternative Hypotheses," *Econometrics* 5, 5.

Chang, Y., Kim, C. S., Miller, J. I., Park, J. Y., and S. Park (2014). "Time-Varying Long-Run Income and Output Elasticities of Electricity Demand with an Application to Korea," *Energy Economics* 46, 334–347.

Dickey, D. and W. Fuller (1979). "Distribution of the Estimators for Autoregressive Time Series with a Unit Root," *Journal of the American Statistical Association* 74, 427–431.

Dickey, D. and W. Fuller (1981). "The Likelihood Ratio Statistics for Autoregressive Time Series with a Unit Root," *Econometrica* 49, 1057–1072.

Engle, R. and C. W. J. Granger (1987). "Cointegration and Error Correction: Representation, Estimation and Testing," *Econometrica* 55, 251–276.

Engle, R., Granger, C. W. J., and J. S. Hallman (1989). "Merging Short- and Long-Run Forecasts: An Application of Seasonal Cointegration to Monthly Electricity Sales Forecasting," *Journal of Econometrics* 43, 45–62.

Hansen, B. (2000). "Testing for Structural Change in Conditional Models," *Journal of Econometrics* 97, 93–115.

Hong, S. D. and C. S. Kim (2018). "Estimating the Price Elasticity of Peak Residential Demand Using High Frequency Data," *Journal of Economic Theory and Econometrics* 29, 48–74.

Hughes, J. E., Knittel, C. L., and D. Sperling (2008). "Evidence of a Shift in the Short-Run Price Elasticity of Gasoline Demand," *Energy Journal* 29, 113–134.

Johansen, S. (1988). "Statistical Analysis of Cointegration Vectors," *Journal of Economic Dynamics and Control* 12, 231–254.

Kim, D. and P. Perron (2009). "Unit Root Tests Allowing for a Break in the Trend Function under Both the Null and the Alternative Hypotheses," *Journal of Econometrics* 148, 1–13.

Kim, J., Jang, M., and D. Shin (2019). "Examining the Role of Population Age Structure upon Residential Electricity Demand: A Case from Korea," *Sustainability* 11, 3914.

Kwiatkowski, D., Phillips, P. C. B., Schmidt, P., and Y. Shin (1992). "Testing the Null Hypothesis of Stationarity against the Alternative of a Unit Root," *Journal of Econometrics* 54, 159–178.

Lee, J. and E. Heo (1998). "A Study on the Long-Run and Short-Run Elasticity of Electricity Demand in Korea," *Journal of Korean Institute of Mineral and Energy Resources Engineers* 35, 149–156.

Lim, K.-M., Lim, S.-Y., and S.-H. Yoo (2014). "Short- and Long-Run Elasticities of Electricity Demand in the Korean Service Sector," *Energy Policy* 67, 517–521.

Miller, J. I. and R. A. Ratti (2009). "Crude Oil and Stock Markets: Stability, Instability, and Bubble," *Energy Economics* 31, 559–568.

Narayan, P. K. and S. Popp (2010). "A New Unit Root Test with Two Structural Breaks in Level and Slope at Unknown Time," *Journal of Applied Statistics* 37, 1425–1438.

Ng, S. and P. Perron (2001). "Lag Length Selection and the Construction of Unit Root Tests with Good Size and Power," *Econometrica* 69, 1519–1554.

Park, J. Y., Kim, I.-M., Kim, C. S., and S. Lee (2011). "A Novel Forecasting Procedure Based on Gap and Catch-Up: Case of the Long-Run Forecast of Electricity Demand in Korea," *Korean Journal of Economic Studies* 59, 113–147.

Perron, P. (1989). "The Great Crash, the Oil Price Shock, and the Unit Root Hypothesis," *Econometrica* 57, 1361–1401.

Perron, P. (1997). "Further Evidence on Breaking Trend Functions in Macroeconomic Variables," *Journal of Econometrics* 80, 355–385.

Perron, P. and G. Rodríguez (2003). "GLS Detrending, Efficient Unit Root Tests and Structural Change," *Journal of Econometrics* 115, 1–27.

Perron, P. and T. Vogelsang (1993). "Erratum: The Great Crash, the Oil Shock and the Unit Root Hypothesis," *Econometrica* 61, 248–249.

Perron, P. and T. Yabu (2009). "Testing for Shifts in Trend with an Integrated or Stationary Noise Component," *Journal of Business & Economic Statistics* 27, 369–396.

Perron, P. and X. Zhu (2005). "Structural Breaks with Deterministic and Stochastic Trends," *Journal of Econometrics* 129, 65–119.

Pourazarm, E. and A. Cooray (2013). "Estimating and Forecasting Residential Electricity Demand in Iran," *Economic Modelling* 35, 546–558.

Said, E. and D. Dickey (1984). "Testing for Unit Roots in Autoregressive Moving Average Models of Unknown Order," *Biometrika* 71, 599–607.

Saikkonen, P. (1991). "Asymptotically Efficient Estimation of Cointegration Regressions," *Econometric Theory* 7, 1–21.

Silk, J. I. and F. L. Joutz (1997). "Short and Long-Run Elasticities in US Residential Electricity Demand: A Co-Integration Approach," *Energy Economics* 19, 493– 513.

Stock, J. H. and M. W. Watson (1993). "A Simple Estimator of Cointegrating Vectors in Higher Order Integrated Systems," *Econometrica* 61, 783–820.

Vogelsang, T. and P. Perron (1998). "Additional Tests for a Unit Root Allowing the Possibility of Breaks in the Trend Function," *International Economic Review* 39, 1073–1100.

Zivot, E. and D. Andrews (1992). "Further Evidence on the Great Crash, the Oil-Price Shock, and the Unit-Root Hypothesis," *Journal of Business and Economic Statistics* 10, 25–44.