

Article

Examining the Role of Population Age Structure upon Residential Electricity Demand: A Case from Korea

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Abstract: In this article, we empirically investigate the impact of the population age structure on electricity demand. Our study is motivated by suggestions from existing literature that demographic factors can play an important role in energy demand. Using Korean regional level panel data for 2000 to 2016, we estimate the long-run elasticities through employing cointegration regression and the short-run marginal effects by developing a panel error correction model. It is worth investigating the Korean case, since Korea is aging faster than any other advanced economy, and at the same time is one of the heaviest energy users in the world. To our knowledge, this is the first study analyzing how the population age structure affects residential electricity demand, based on regional data in Korea. Our analysis presents the following results. First, an increase in the youth population raises the residential electricity demand in the short- and long-run. Second, an increase in the population of people aged 65 and over also increases this electricity demand in the short- and long-run. Third, among the group of people aged 65 and over, we further investigate the impact of an older population group, aged 80 and over, but separately, on their residential electricity demand. However, in general there is no strong relationship in the short- and long-run.

Keywords: residential electricity demand; demographics; age structure; cointegration regression; panel error correction model

1. Introduction

Korea has been confronting the critical demographic issue of an aging population. According to Statistics Korea, the Korean statistics authority, the current proportion of the population aged 65 and above is 13.2%, which is almost double the value of 7.2% recorded in 2000 [1]. An aging society is a prevailing phenomenon in developed countries; however, the trend in Korea is too rapid. According to the World Bank, as of 2016, Ireland, Cyprus and Russia are at par with Korea, at approximately 13% [2]. It took 52 years to double the population of people 65 years and over in Russia and Cyprus, and in Ireland, it took more than 52 years [2]. However, in Korea it happened in only 18 years. To make matters worse, this trend will be continued. Statistics Korea anticipates that the proportion of the population aged 65 and over will be 24.5% of the total population by 2030 [1].

Age structure, particularly population aging, affects the economy in various aspects. It could cause a decline in the rate of economic growth by lowering the labor-force participation and saving rates [3]. It could also affect consumption, investment, money demand [4], domestic savings, the current account [5] and the financial and money markets [6–9].

Recent research has contributed to the understanding of the relationship between demographics and energy demand [10–13]. In the modern economy, energy sources are essential for our daily life.

From morning to night we use light, heating, cooling, we drive cars, take subways and so on. All of these facilities and vehicles need energy in whatever shape and form it takes. However, electricity is the most important among them, due to its convenience, safety and relatively low price. Because of these advantages, the final destination of many kinds of energy sources is electricity.

There are many determinants of electricity demand, such as income levels, rising temperatures in summer, falling temperatures in winter, the wide distribution of electricity appliances, and so on. Besides these well-known factors, socio-demographic factors can play an important role in electricity demand. Among them, the population age structure is considered to be a major factor.

The role of age structure in electricity demand has been studied extensively in the existing literature, but the results are mixed, depending on the data and the applied methodologies (For the role of demographic change on the environment, see Cole and Neumayer [14], Dalton et al. [15], Fan et al. [16], Kronenberg [17], Liddle and Lung [18], Menz and Kühling [19] and Menz and Welsch [20]). One thread of articles insists that aging populations increase energy demand [21,22]. These articles suggest two prominent reasons. First, aging populations tend to stay inside their houses longer, and second, they usually need more thermal comfort, in terms of heating and cooling, in order to maintain their health conditions [21–24].

Bardazzi and Pazienza [10] analyze the influence of population aging on energy expenditure using repeated cross-section data from Italy. They employ pseudo-panel regression and find that aging causes an increase in energy expenditure. Elnakat et al. [11] find that energy demand reaches the maximum value at the median age of over 40, since this group stays at home longer. Using Chinese urban survey data and this same reasoning, Zhou and Teng [25] contend that aging households consume more electricity.

Kim and Seo [26] and Roberts [21] find that aging can increase electricity demand due to the environment that the aging population faces. Old people are more sensitive to weather; in order to maintain their health, they consume more electricity for heating and cooling. Additionally, old people tend not to change their inefficient electricity appliances, and this can increase electricity demand.

Liddle [27] analyzes the impact of population age structure on residential electricity demand, based on 22 Organisation for Economic Co-operation and Development (OECD) countries. (OECD is intergovernmental economic organization with 36 countries, as of 2019. Most of OECD members are recognized as developed countries). Since demographic impact is long-run phenomenon, and cointegrated relationship in the sample supports the long-run equilibrium, Liddle applies fully modified ordinary least squares (FMOLS), and finds that having a population aged 70 and over leads to an increase in residential electricity.

Yamasaki and Tominaga [28] investigate the Japanese case. They suggest that the number of households, income level, residential type, durable goods, consumption patterns and others are channels of the aging effect. Considering these factors, the authors expect aging to increase energy demand. York [29] conducts a panel regression model with panel-corrected standard errors (PCSE), using national data from 14 European Union (EU) countries for the period 1960–2000. Unlike the previous literature, they focus on commercial energy use. They conclude that a 1% increase in the population aged 65 and over leads to about a 0.9% increase in commercial energy use.

The other thread of articles insists that aging populations decrease energy demand [12,13,30,31]. They attribute the results to a lower intensity of energy consumption. Even though old people stay inside longer, they do not use energy appliances much. Additionally, an aging population has negative effects on the supply side and disposable income. Therefore, reduced disposable income leads to lowering energy consumption.

Brounen et al. [32] investigate the Dutch case. They study the effects of household characteristics on electricity demand using a large amount of household survey data. They run the cross-sectional regression model and find that aging causes a decrease in electricity consumption. However, on the other hand, households with children and youth lead to an increase in electricity consumption, because

the youth watch more TV, use PCs, and are heavy users of gaming devices, which is described as the “Nintendo-effect.”

Fu et al. [12] explore the demographic effect on residential energy consumption (REC) based on the China Urban Household Survey (CUHS) from 2005 and 2010. They find that per capita REC is not sensitive to age structure before 60 years old, whereas the per capita REC of people aged 60 and over decreases sharply, from which they conclude that population aging may have some effect on REC. Garau et al. [31] employ the calibrated Overlapping Generations (OLG) Equilibrium Model. Adopting Italy as a case study, they find that a pronounced aging population causes a reduction in energy consumption through the supply channel.

Ota et al. [13] focus on the demographic effects on energy demand. They employ a panel data analysis of residential electricity at the Japanese prefecture level. The demographic variables they consider are: The proportion of people aged 65 or above to the total population and the total fertility rate. In their article population aging has negative effects on electricity demand, but the total fertility rate has no effects.

In this article, we investigate how age structure affects the Korean electricity demand using regional panel data. The reason we analyze the energy-demography relationship in Korea and its significance on energy policy is as follows. Korea is an advanced economy, and the economic growth rate is still solid. The economic structure is transitioning to the service sector, however the industrial sector is still larger, which makes Korea still a heavy energy user. Furthermore, as previously mentioned, Korea is aging faster than any other developed country. These backgrounds indicate that examining the influence of the population age structure upon energy demand is a very important agenda. However, we rarely find any related literature of the Korean case. In order to design a more precise energy demand policy, and to improve the accuracy of energy demand forecasts, this population age structure should be fully considered. In spite of significant evidence from related literature, those factors are still not taken into consideration in the primary statistical model in the Korean National Basic Plan on Electricity Demand [32].

The contribution of our study is three-fold. First, we construct regional panel data of Korea and investigate the relationship between energy demand and the population age structure in Korea. Most of the previous studies use nation-wide level data [26,27,29] or micro-household level data for analyzing the energy-demography relationship [10–12,25,30]. Using nation-wide data is beneficial to macro analysis for the whole country, incorporating economic dynamics. However, usually nation-wide data is criticized by its small sample property. On the other hand, using micro-household level data enables researchers to obtain a large sample and more detailed information regarding household characteristics. However, it is too costly to track each household for the long period, and thus it usually lacks time information. Against the background, we use Korean regional level data to fill the gap between using nation-wide and micro-household level data. To our knowledge this is the first paper to examine how population age structure, especially youth and elderly population, affects residential electricity demand in Korea, using regional panel data. Second, from a methodological standpoint, we estimate the energy-demography relationship by employing sophisticated panel econometric models, a fully modified ordinary least squares for the long-run effect and a panel error correction model for the short-run effect. When long time series information is employed in panel data, researchers should account for any short- and long-run effects in their econometric model. However, previous studies do not consider these time period effects [27,29]. Third, we propose an effective energy policy in terms of the demand and supply side of energy based on our empirical results.

This paper is organized as follows. Section 2 introduces the status-quo of the age structure and energy consumption in Korea. Section 3 illustrates the data and econometric methodologies adopted in the analysis. Section 4 presents the empirical results. Section 5 concludes the study.

2. Population Age Structure and Energy Consumption in Korea

2.1. Population Age Structure in Korea

An aging society is considered to be a problem for the developed world. However, it is a bigger problem for the emerging world, since the pace of aging is much more rapid in these countries. Developed countries have been experiencing population aging for a long time; therefore, they have had enough time and resources to adapt to it. On the other hand, emerging countries are relatively incapable of dealing with it, due to the rapid transition and lack of preparation.

Korea, a newly developed economy, suffers from the same problem. Figure 1 shows the change in age structure of the Korean population [1]. The blue line indicates the proportion of the youth, aged 0 to 14, against the total population. The red line indicates the proportion of those in their prime, aged 15 to 64. The green line is the proportion of the old, aged 65 and over. A clear upward trend of the aging and a downward trend of the youth can be seen. The aging population has been continuously increasing; it comprised 13.8% of the total population in 2017. On the other hand, the share of the youth population began to decline from 1966, after reaching a peak of 43.9%. The prime age has also gradually increased until 2016, but begins to decline from 2017 after reaching a peak of 73.4%. The shaded area indicates expected values in the future, and we can see a sharp increase in the old and a sharp decrease in those in their prime. Korea had already become an aging society in 2000, and has become an aged society in 2017. The transition took only 17 years (According to the United Nations (UN) standards, an aging society is defined as a country in which the share of the population aged 65 and over exceeds 7% of the total population, and an aged society exceeds 14% of the total population). The problem is that this trend is extremely rapid relative to that of France (115 years), Germany (40 years), and the USA (73 years). It is widely acknowledged that population aging causes a shrinking labor force and large burdens on social security systems for the elderly, such as pension, health care and this can lead to poverty. These two issues are interconnected and trigger the overall macroeconomic problem. Economic growth can be slowed, not solely from a shrinking labor force, but also through consumption constraint. To deal with the rising burdens on social security systems, governments have to increase the tax rate. To make matters worse, in Korea, rising housing prices have lowered the marriage rate, which is affecting the fertility rate, and thus accelerating population aging.

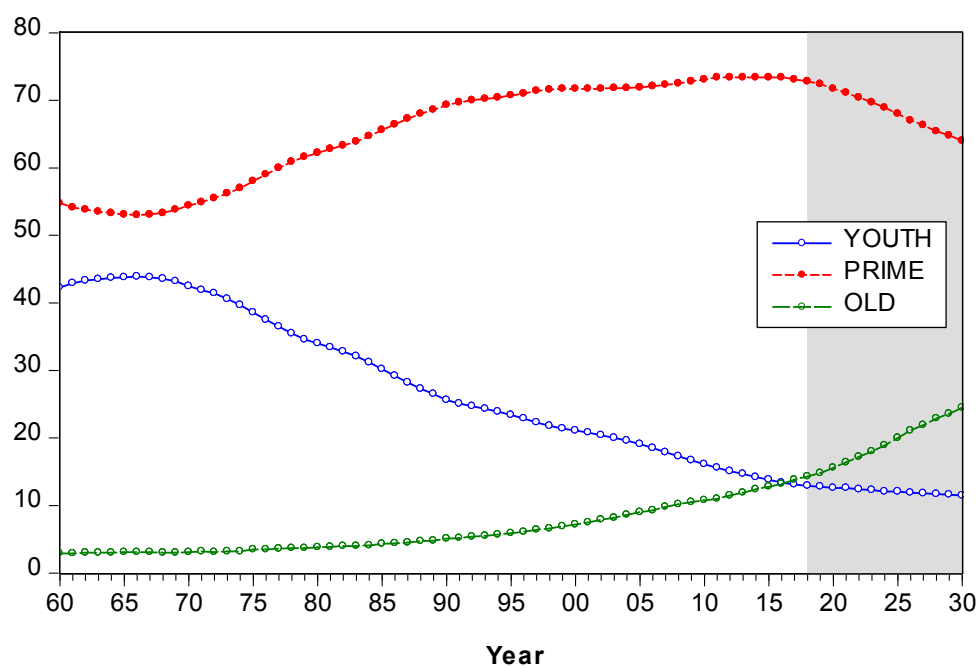


Figure 1. Population Age Structure in Korea. (% of total population).

According to the World Development Indicator, the fertility rate of Korea was recorded as 1.17 in 2016, which is the lowest in the world [33]. The government has been tackling these problems for a long time by introducing a series of policies. These policies mainly include childcare allowances, non-financial support for childcare, promotion of labor participation for women, and a reduced burden for newly married households. However, the results are not fruitful.

2.2. Energy Consumption in Korea

Due to the previously mentioned advantages of electricity, the demand for electricity has risen rapidly. Figure 2 shows the proportion of final energy consumption in Korea by its sources [34]. The green line (left axis) accounts for the oil consumption, and the blue and red lines (right axis) account for the coal and electricity consumption, respectively. In the past, oil and coal were the larger proportion, but as time went by, electricity consumption increased gradually. The graph shows the clear downward trend of oil, which reached its highest value of 68.2% in 1994 and declined to the lowest value of 48.1% in 2014, a huge drop of about 20%. Coal recorded 26.4% in 1990 but declined by 11.8% and ends up at 14.6%. Unlike the other two energy sources, electricity shows an upward trend. In 1990 electricity was only 10.8% of total final consumption, which was much less than coal consumption. However, it has increased gradually and was recorded as about 20% in 2016, which is almost double the 1990 value.

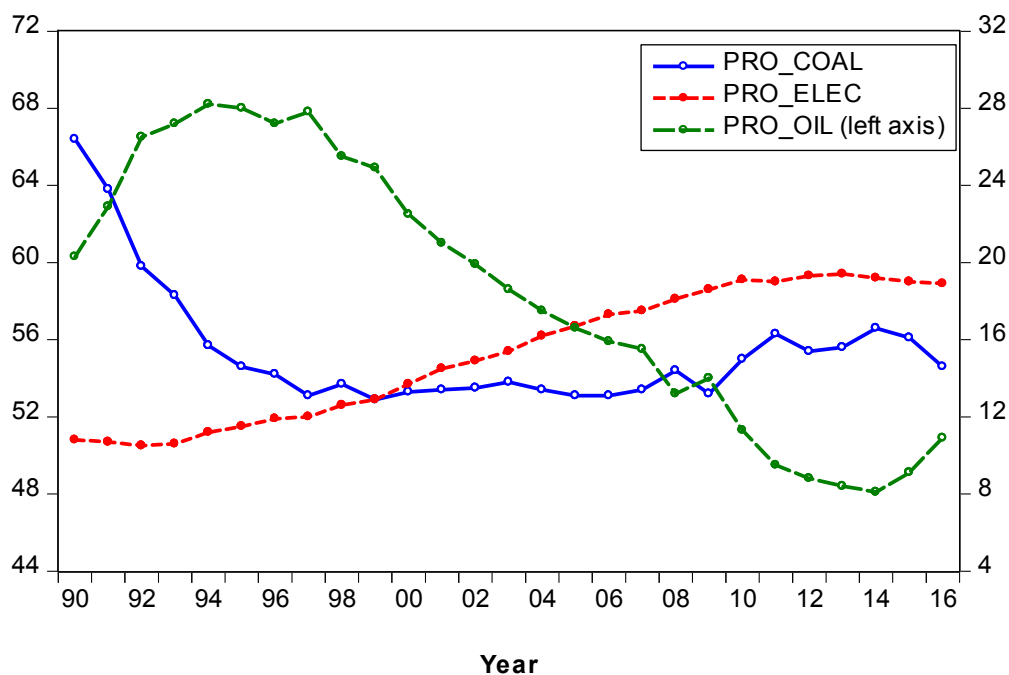


Figure 2. Proportion of Energy Consumption in Korea (% of total energy consumption).

Figure 3 shows the residential electricity consumption in Korea [34]. In 1998, the consumption was about 32,000 GWh, and it grew continuously to around 66,000 GWh. It took 18 years for the residential electricity consumption to double. Many determinants played a role in this rapid increase. Among them, low electricity prices and climate change are considered to be important factors.

The International Energy Agency (IEA) [35] gives us the statistics of the residential electricity price for 30 OECD countries (Figure 4), and the Korean price is ranked at the 4th lowest level. The sample mean is approximately \$185/MWh and the Korean price is \$119/MWh. Even Japan, a neighbor of Korea, records \$222/MWh, which is almost double.

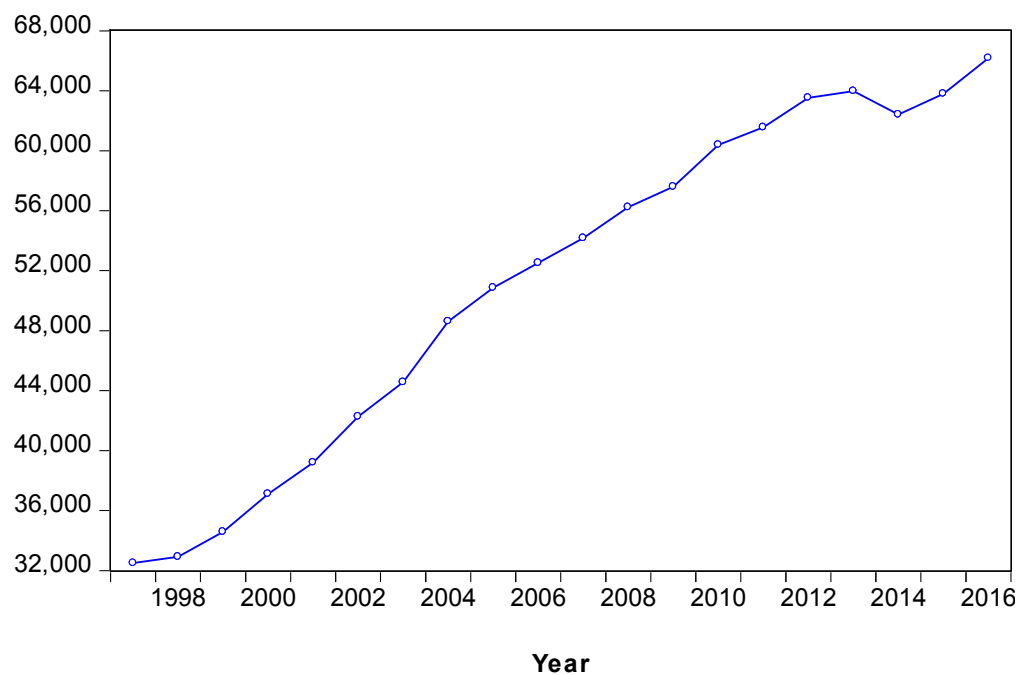


Figure 3. Residential Electricity Consumption in Korea (GWh).

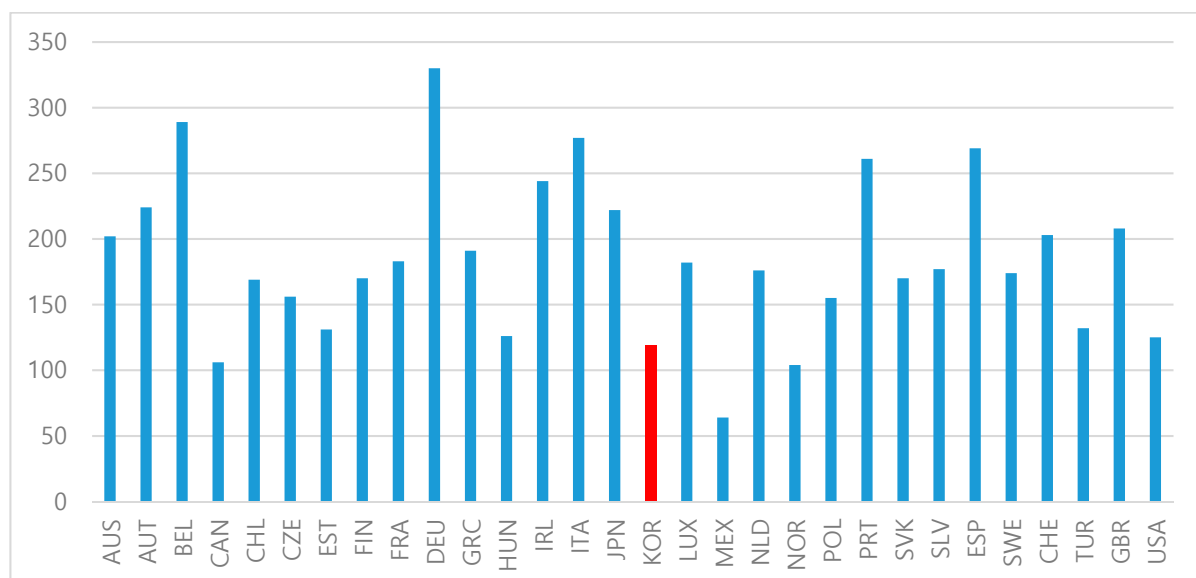


Figure 4. Residential Electricity Price of Organisation for Economic Co-operation and Development (OECD) countries. (\$/MWh).

Climate conditions also push up the electricity demand. Figure 5 displays the cooling degree day (CDD) and heating degree day (HDD) in Seoul, the capital of Korea [36]. CDD and HDD are the most widely used indicators for quantifying energy demand for cooling and heating.

The higher the value, the greater the cooling and heating demands are. According to the statistics, CDD recorded 674 in 1990 and rose by 45% to 976 in 2016. HDD reached 2557 in 1990 and rose by 16% to 2967 in 2012. We can observe the upward trend in both indicators, although there are some fluctuations.

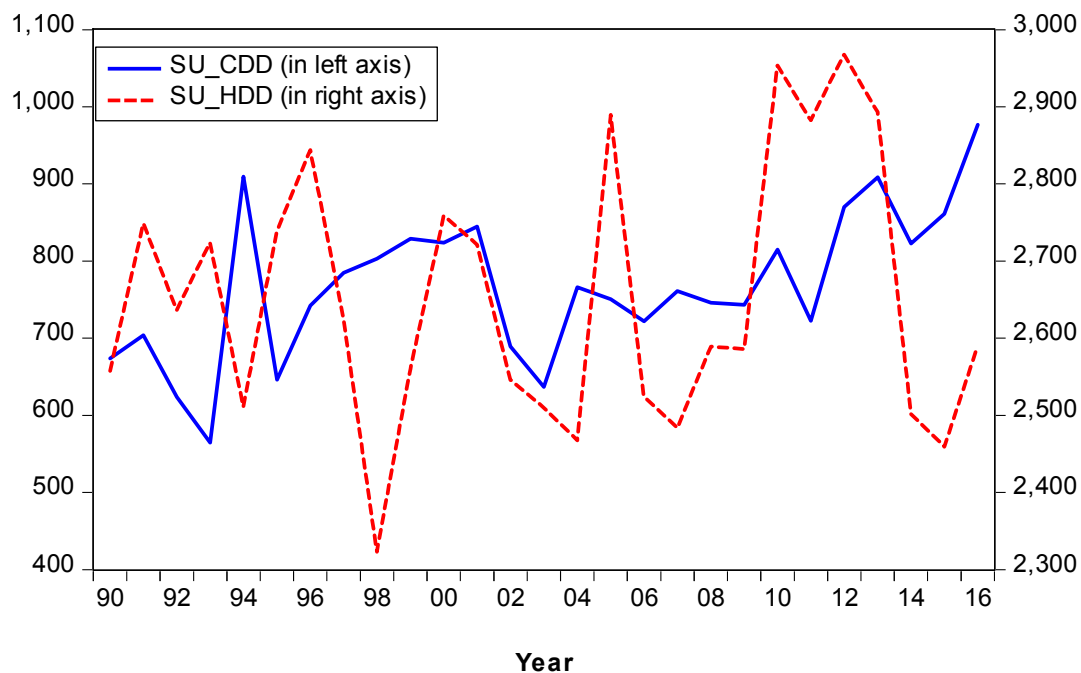


Figure 5. Cooling degree days (CDDs) and heating degree days (HDDs) in Seoul.

3. Econometric Methodology and Data Collection

3.1. Data Collection

Electricity is the major energy source for residential use in Korea. In this section, we discuss the effect of the population age structure and economic factors on residential electricity demand in Korea. For this study's econometric model, the sixteen Korean provinces represent the individual units. The time-series for each unit has seventeen annual data points, for each year from 2000 to 2016, inclusive. Though we have Korean regional residential electricity consumption data from 1990, we only use the samples from 2000, based on three reasons. First, Korean provinces have been divided into sixteen regions since 1998 (Seoul, Busan, Daegu, Incheon, Gwangju, Daejeon, Ulsan, Gyeonggi, Gangwon, Chungbuk, Chungnam, Jeonbuk, Jeonnam, Gyeongbuk, Gyeongnam and Jeju). Before 1998, Ulsan was a part of Gyeongnam, thus using the relevant data from those prior periods could distort the empirical results. Second, we only have the residential electricity consumption of Ulsan since 2000. Third, in the late 1990s, Korea experienced the Asian financial crisis and the liberalization of the oil market. Oil had been the primary energy source until these two major exogenous shocks caused an economic structural change. We finally estimate the FMOLS for long-run coefficients and the panel error correction model (PECM) for short-run coefficients based on the results of the panel unit-root and cointegration tests (For the same empirical analysis strategy in the field of energy economics, see Apergis and Payne [37,38]).

To discuss the effect of the population age structure and the economic factors on electricity demand, we consider the following model:

$$E_{it} = f(\text{Energy}, \text{Econ}, \text{Climate}, \text{Age}) \quad (1)$$

The data we use for the empirical analysis are divided into three groups. The first group is energy and economic variables, the second group is climate variables, and the third group is demographic variables. For the energy variables, we use residential electricity consumption (E), residential real electricity price (RP), and the consumer price index (CPI) for oil products (OP). For the economic variable, we use the real value (Y) of the gross regional domestic product (GRDP) in 2010. The data for regional residential electricity consumption is obtained from the Korea Energy Statistical Information System (KESIS) of Korean Energy Economics Institute (KEEI) [39]. We create the residential electricity

price in real terms by deflating the nominal residential electricity price from the Korea Power Exchange (KPX) [40] by regional CPI obtained from the Korean Statistical Information Service (KOSIS) [41]. The CPI for oil products and GRDP are taken from the KOSIS [41,42] (In Korea, urban natural gas is widely used for heating, and can be a substitute for electricity. However, the regional level gas price is not available. Korea practically imports total fossil fuel from overseas, and the correlation between the national price level of oil and gas is over 0.96, so we have chosen the regional oil price for general substitutes).

We include the climate variables of heating degree day (HDD) and cooling degree day (CDD), which are taken from the Korea Meteorological Administration (KMA), to capture the temperature effect [36]. The demographic variables include the youth dependency ratio, the share of the population from ages 0 to 14 to prime age (P0014); old dependency ratio, over 65 to prime age (P65); old dependency ratio, between 65 and 79 to prime age (P6579); and old dependency ratio, over 80 to prime age (P80) (Ota et al. [13] include the fertility rate as an explanatory variable. We replace the fertility rate with the youth dependency ratio). They are obtained from the KOSIS [1]. In summary, we construct a balanced panel data set comprising 272 observations from 16 regions for the period 2000 to 2016.

Table 1 describes the summary statistics for the variables in logarithms. Figures 6–9 illustrate the age structure for each region in 2016.

Table 1. Summary statistics (Observations = 272).

Category	Var	Mean	Std. Dev	Skewness	Kurtosis	Source
Energy	E	7.78	0.78	0.58	3.60	KESIS
Economy	RP	0.31	0.09	0.42	2.04	KPX
	OP	4.58	0.21	−0.11	1.79	KOSIS
	Y	17.75	0.80	0.40	3.33	
Climate	HDD	7.76	0.19	−0.62	2.94	KMA
	CDD	6.64	0.16	−0.42	3.43	
Age Structure	P0014	3.19	0.19	−0.23	2.21	KOSIS
	P65	2.68	0.39	−0.16	2.20	
	P6579	2.49	0.37	−0.19	2.22	
	P80	0.90	0.50	−0.03	2.23	

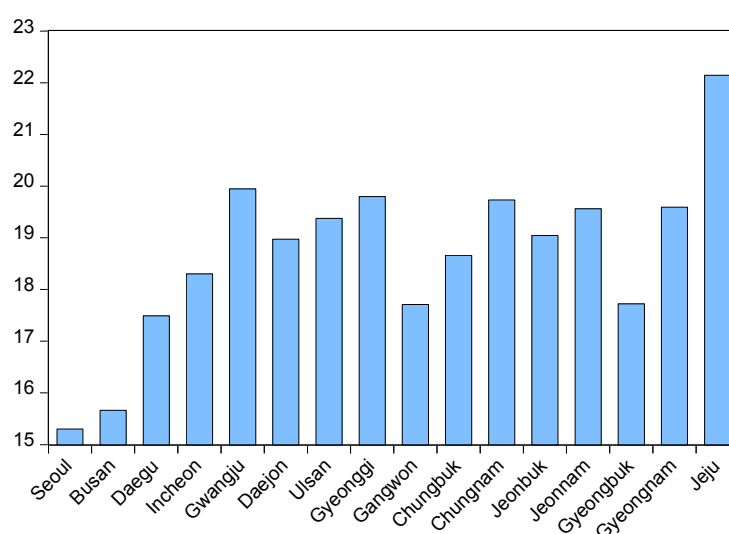


Figure 6. Youth dependency ratio for each region in 2016.

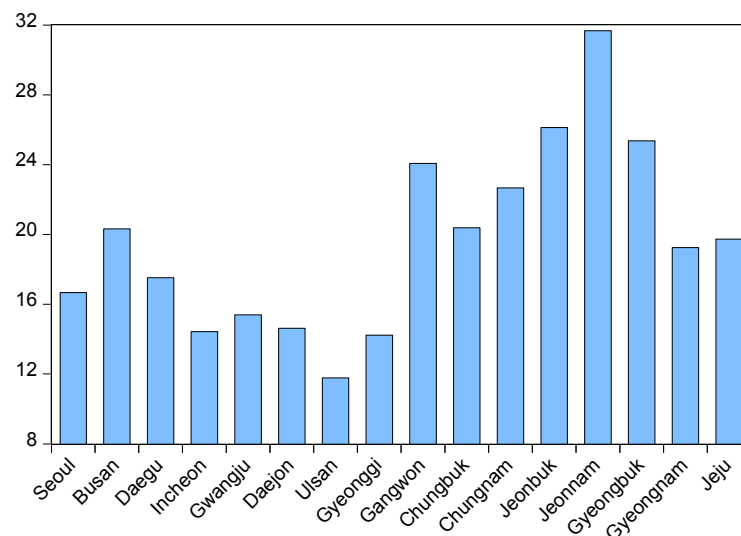


Figure 7. Old dependency ratio, over 65, for each region in 2016.

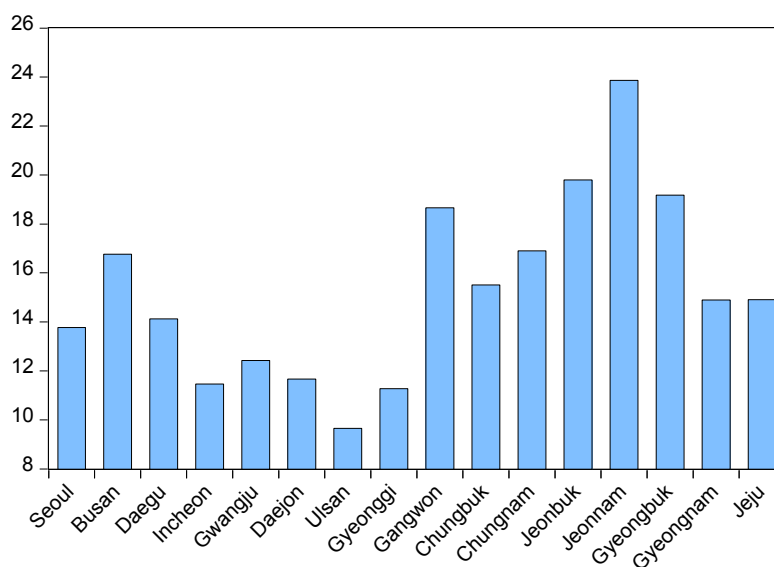


Figure 8. Old dependency ratio, 65 to 79, for each region in 2016.

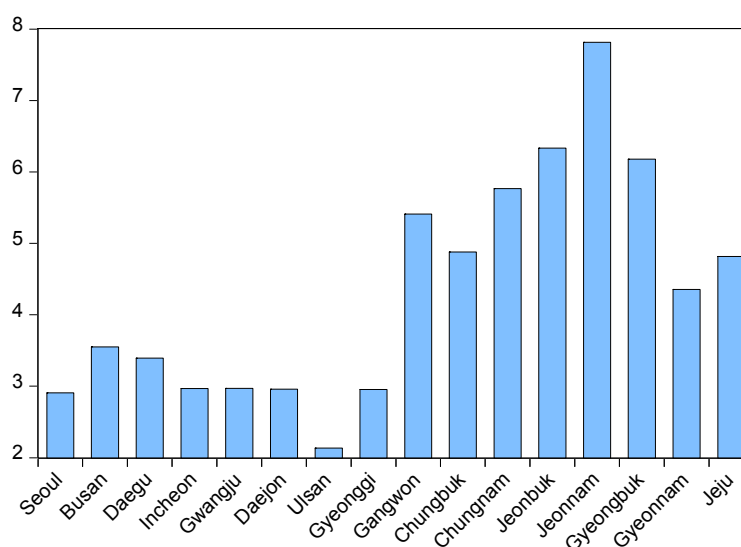


Figure 9. Old dependency ratio, over 80, for each region in 2016.

3.2. Panel Unit Root and Cointegration Tests

In this section, we briefly introduce panel unit root and cointegration tests (For the overview of two econometric tests, see Baltagi [43] and Banerjee [44]). Because of the relatively long time-series information we have, the panel unit root test should be conducted. In this article, we consider three types of test which are most widely used, the IPS [45] test and Maddala-Wu Fisher-type augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests [46]. The following Equation (2) is regression model for testing the unit root hypothesis.

$$\Delta y_{it} = \alpha_i + \beta_i y_{it-1} + \varepsilon_{it} \quad (2)$$

The IPS test evaluates the null hypothesis, that each individual time series in the panel contains a unit root, against the alternative hypothesis that a non-zero fraction of the individual time series is stationary.

$$H_0: \beta_i = 0 \text{ for all } i; H_1: \beta_i < 0, i = 1, 2, \dots, N_1, \beta_i = 0, i = N_1 + 1, N_2 + 1, \dots, N$$

Maddala and Wu [27] propose an alternative way of testing the unit root hypothesis, Fisher-ADF and Fisher-PP test statistics, which combines the p-values from unit root tests for each individual i as follows.

$$\Delta P = -2 \sum_{i=1}^N \ln p_i \quad (3)$$

Let p_i be the asymptotic p-value of a unit root test for an individual time series i , and let P be the combination of the p-values. Note that P is distributed as a χ^2 with $2N$ degrees of freedom as $T_i \rightarrow \infty$ for finite N .

Verifying the existence of unit roots from the previous tests, we should conduct a panel cointegration test. Among various tests, we follow Pedroni [47,48] and Kao [49], the most widely used tests, to detect the long-run equilibrium relationship between these variables. The two tests are a residual-based cointegration test, which begins with the following spurious least square dummy variable (LSDV) regression model for the panel data (For the more detailed explanation of the two econometric tests, see Baltagi [43] and Banerjee [44]).

$$y_{it} = \alpha_i + \beta x_{it} + \varepsilon_{it}, i = 1, 2, 3, \dots, N, t = 1, 2, 3, \dots, T \quad (4)$$

Kao [49] proposes a DF and ADF-type unit root test for ε_{it} as a test for the null of no cointegration. He shows that the asymptotic distributions of the test statistics converge to a Standard Normal $N(0,1)$ by the sequential limit theorem. On the other hand, Pedroni [47,48] proposes several tests for cointegration that allows for heterogeneous individual effects and trend coefficients across each individual. Pedroni shows that the standardized statistic is asymptotically normally distributed.

3.3. Panel Cointegration Regression

In the empirical analysis with the panel data, the nonstationarity of the time series is an important issue for correct statistical inference. When all of the variables are cointegrated, we should estimate the long-run cointegration parameter, β from above Equation (4), to account for the nonstationarity property. For this reason, we employ the fully modified ordinary least squares (FMOLS) proposed by Pedroni [50]. He finds that the FMOLS estimator exhibits relatively minor size distortion in small samples and it is asymptotically unbiased for the standard case without intercepts, as well as the fixed effects model with heterogeneous intercepts [50]. Additionally, t -statistics for the FMOLS estimator of β from above Equation (4) is shown to be asymptotically standard normal.

3.4. Panel Error Correction Model

Following the seminal work of Engle and Granger [51], we specify the panel error correction model (PECM) to examine the short-run relationship between variables. After estimating Equation (2) by FMOLS, we estimate the PECM of the form:

$$\Delta y_{it} = \alpha_i + \beta \Delta x_{it} + \gamma \varepsilon_{it-1} + e_{it} \quad (5)$$

where γ is the speed of adjustment coefficient and ε_{it-1} is called the error correction term (ECT). If γ shows a negative value with statistical significance, the PECM is well estimated.

4. Results

4.1. Long-Run Analysis

In this section, we discuss the results from above mentioned unit root and cointegration tests. Table 2 displays the p-value results from the three types of unit root tests. We take logarithms for all of the variables and the maximum lag structure is three, considering that the sample is in annual frequency. The unit root null hypothesis cannot reasonably be rejected under the 5% significance level, in the first and third group of variables, according to the IPS and the Maddala-Wu Fisher-type test. The second group of variables, *HDD* and *CDD*, are found to be stationary variables according to the same test. All the variables, besides *HDD* and *CDD*, are found to be *I* (1), integrated of order 1, according to the unit root test results in Table 2.

Table 2. Unit root test results.

Var	IPS	Fisher-ADF	Fisher-PP
E	0.99	1.00	0.99
ΔE	0.00	0.00	0.00
RP	0.99	1.00	0.72
ΔRP	0.00	0.00	0.00
OP	0.38	0.83	0.82
ΔOP	0.00	0.00	0.00
Y	0.64	0.34	0.00
ΔY	0.00	0.00	0.00
HDD	0.00	0.00	0.00
CDD	0.00	0.00	0.00
P0014	1.00	0.99	1.00
$\Delta P0014$	0.00	0.00	0.00
P65	0.16	0.10	0.99
$\Delta P65$	0.00	0.00	0.01
P6579	0.98	0.94	0.99
$\Delta P6579$	0.00	0.00	0.00
P80	1.00	1.00	0.97
$\Delta P80$	0.00	0.00	0.00

With the seven nonstationary variables, we test the cointegration hypothesis to identify the long-run relationship. We perform the previously mentioned Kao and Pedroni tests for these two groups of variables. Equation (6) is the test equation.

$$E_{it} = \alpha_i + \beta_1 RP_{it} + \beta_2 OP_{it} + \beta_3 Y_{it} + \beta_4 P0014_{it} + \beta_5 OLD_{it} + \varepsilon_{it} \quad (6)$$

We use *P65*, *P6579* and *P80* for describing the *OLD* variable, however, the linear correlation between the three variables is 0.97. To avoid this problem, we combine *E*, *RP*, *OP*, *Y*, *P0014* and *P65* as Group 1, *E*, *RP*, *OP*, *Y*, *P0014* and *P6579* as Group 2 and *E*, *RP*, *OP*, *Y*, *P0014* and *P80* as Group 3. Tables 3–5 display the Pedroni's cointegration test results and Table 6 shows the Kao's. In the Pedroni

test, 6 out of 11 statistics reject the null of no cointegration, and in the Kao test, the t-statistics reject the null for all the groups. Hence we reasonably conclude that the null of no cointegration can be rejected, and there is a long-run equilibrium relationship among variables.

Table 3. Pedroni cointegration test results for Group 1.

Types	Statistics	<i>p</i> -Value	Weighted Statistics	<i>p</i> -Value
Panel v	0.46	0.32	−0.38	0.65
Panel rho	3.43	0.99	3.46	0.99
Panel PP	−5.05	0.00	−5.36	0.00
Panel ADF	−3.37	0.00	−3.64	0.00
Group rho	5.37	0.99		
Group PP	−8.67	0.00		
Group ADF	−3.16	0.00		

Table 4. Pedroni cointegration test results for Group 2.

Types	Statistics	<i>p</i> -Value	Weighted Statistics	<i>p</i> -Value
Panel v	0.35	0.36	−1.25	0.89
Panel rho	3.30	0.99	3.36	0.99
Panel PP	−4.78	0.00	−6.01	0.00
Panel ADF	−3.49	0.00	−3.44	0.00
Group rho	5.11	1.00		
Group PP	−9.90	0.00		
Group ADF	−3.49	0.00		

Table 5. Pedroni cointegration test results for Group 3.

Types	Statistics	<i>p</i> -Value	Weighted Statistics	<i>p</i> -Value
Panel v	0.80	0.21	−0.77	0.78
Panel rho	2.06	0.98	1.83	0.97
Panel PP	−8.07	0.00	−7.31	0.00
Panel ADF	−5.58	0.00	−5.59	0.00
Group rho	3.90	1.00		
Group PP	−12.11	0.00		
Group ADF	−4.56	0.00		

Table 6. Kao cointegration test results.

Groups	t-Statistics	<i>p</i> -Value
Group 1	−4.68	0.00
Group 2	−4.61	0.00
Group 3	−5.23	0.00

Given the presence of a cointegration relationship, the FMOLS method is applied to determine the long-run relationship. Table 7 displays the long-run coefficient estimates of Equation (6) based on FMOLS.

Since all variables are expressed as natural logarithms, the coefficients are considered to represent elasticity. We firstly discuss the impact of the age structure variables. Estimation results show that a 1% increase in the youth dependency ratio increases residential electricity consumption by 0.87–0.89%; a 1% increase in the old age dependency ratio for individuals aged 65 and over increases the consumption by 0.45%; a 1% increase in the old age dependency ratio for individuals aged 65 to 79 increases consumption by 0.37%; on the other hand, a 1% increase in the old age dependency ratio for those aged 80 and over decreases residential electricity consumption by 0.1%. However, estimates of this old age dependency ratio for those aged 80 and over are not statistically significant. From the results, we

can see that the youth population has a positive and a larger effect upon electricity demand than the old population. A possible explanation for the positive effect of youth on the electricity demand is the “Nintendo-effect” [30]. Children usually watch more TV, use PCs, and are heavy users of game devices.

Table 7. Fully modified ordinary least squares (FMOLS) long-run coefficient estimates.

Var	Group 1	Group 2	Group 3
P0014 _{it}	0.87 ***	0.89 ***	0.89 ***
P65 _{it}	0.45 ***		
P6579 _{it}		0.37 ***	
P80 _{it}			−0.10
RP _{it}	−0.64 ***	−0.57 ***	−0.62 ***
OP _{it}	0.06	0.04	0.10 **
Y _{it}	0.20 ***	0.25 ***	0.53 ***

Notes: ** Significance at 5%, *** significance at 1%.

Furthermore, children do not have enough money to spend outside the home to meet their needs. Additionally, population aging generally has a positive effect on residential electricity consumption. Previous studies support our results [10,11,21,22,25–29]. However, we verify that the effect is heterogeneous between old age groups. A possible explanation is that the elderly tend to stay at home longer, and are more concerned about heating and cooling.

Next, we discuss other non-demographic control variables. The results of Groups 1 to 3 indicate that a 1% increase in residential electricity price decreases residential electricity consumption by 0.57 to 0.64%; a 1% increase in oil price increases electricity consumption by 0.04% to 0.10%, which supports conventional economic theory of negative own-price effect and positive cross-price effect. Further, this could be evidence that electricity consumption is a substitute for overall fossil fuel consumption when the fossil fuel price increases. Both price elasticity is inelastic and cross-price elasticity is lower than own-price elasticity. We find that the results are similar to Zhou and Teng [26] in terms of own-price elasticity. In their article, using the annual urban household survey data of Sichuan Province in China from 2007 to 2009, own-price elasticity is found to be about −0.50%. In terms of cross-price elasticity, Ota et al. [13] show similar results. Using Japanese regional panel data, they include residential gas, whereas we include oil, as substitutes for electricity, yielding a cross-price elasticity of about 0.12.

For the income elasticity, we find that a 1% increase in real income leads to an increase in electricity consumption of 0.20%, 0.25% and 0.53%, respectively, which is inelastic. Compared with previous literature, our results are in the reasonable range. Zho and Teng [25] find that income elasticities are 0.14 to 0.34. Brounen et al. [30] show 0.11 based on Dutch household data and Ota et al. [13] show 0.08 for Japanese data. Estimated income elasticity from household survey data usually tends to be smaller than regional and macro data, since the effect is short-run. However, Liddle [27], applying the same method as ours based on twenty-two OECD countries, shows an income elasticity of 0.62.

4.2. Short-Run Analysis

According to the previous unit-root test, all of the variables are found to have nonstationary properties, except the climate variables. We should transform nonstationary variables into stationary variables by taking the natural log first difference. We further transform the climate variables in order to be consistent with the dependent variable. We estimate the following PECM model for short-run coefficients. The names and definitions of these variables have been explained previously in Section 3.1. The OLD variable represents P65, P6579 and P80 and the ECT variable represents the error correction term generated by Equation (6).

$$\Delta E_{it} = \alpha_1 + \beta_1 \Delta Y_{it} + \beta_2 \Delta RP_{it} + \beta_3 \Delta OP_{it} + \beta_4 \Delta HDD_{it} + \beta_5 \Delta CDD_{it} + \beta_6 \Delta P0014_{it} + \beta_7 \Delta OLD_{it} + \beta_8 ECT_{it-1} + u_{it} \quad (7)$$

We additionally change the Equation (7) slightly to Equation (8) by dividing the residential electricity price by the oil price in order to reflect the relative price effect.

$$\Delta E_{it} = \alpha_i + \beta_1 \Delta Y_{it} + \beta_2 \Delta (RP_{it}/OP_{it}) + \beta_3 \Delta HDD_{it} + \beta_4 \Delta CDD_{it} + \beta_5 \Delta P0014_{it} + \beta_6 \Delta OLD_{it} + \beta_7 ECT_{it-1} + u_{it} \quad (8)$$

Models 1 to 6 in Table 8 show the estimation results of PECM. All of the variables are log differenced, and 240 observations are used. We apply robust standard error clustered by individual cross-section. First of all, the sign of ECT is negative and statistically significant, which means the error correction model is functioning well.

Table 8. Panel error correction model (PECM) short-run coefficient estimates.

Var	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
$\Delta P0014_{it}$	0.56 ***	0.57 **	0.58 ***	0.57 ***	0.71 ***	0.72 ***
$\Delta P65_{it}$	0.34 ***	0.34 ***				
$\Delta P6579_{it}$			0.26 ***	0.26 ***		
$\Delta P80_{it}$					0.02	0.02
ΔY_{it}	0.27 ***	0.26 ***	0.27 ***	0.27 ***	0.36 ***	0.36 ***
ΔRP_{it}	−0.11 **		−0.07		−0.14 ***	
ΔOP_{it}	0.08 ***		0.08 ***		0.10 ***	
$\Delta (RP_{it}/OP_{it})$		−0.09 ***		−0.08 ***		−0.10 ***
ΔHDD_{it}	0.03 *	0.03 *	0.03 *	0.03 *	0.04 **	0.04 **
ΔCDD_{it}	0.05 ***	0.04 ***	0.05 ***	0.05 ***	0.05 ***	0.05 ***
ECT_{it-1}	−0.42 ***	−0.42 ***	−0.42 ***	−0.42 ***	−0.51 ***	−0.52 ***
Adj-R ²	0.57	0.57	0.57	0.57	0.57	0.57

Notes: * Significance at 10%, ** significance at 5%, *** significance at 1%.

The overall result is qualitatively in line with previously estimated long-run elasticities. Among the population age structure variables, the youth dependency ratio, P0014, shows positive values between 0.56–0.72, which are statistically significant under the 1% significance level. Since all the variables are log-difference transformed, we can interpret that a 1%p increase in P0014 leads to a 0.56–0.72%p increase in residential electricity consumption, which is a marginal effect. The “Nintendo-effect” could be a good explanation for the result [30].

The estimated coefficients of the old age dependency ratio, P65 and P6579 show a positive value, 0.34 and 0.26, respectively, which could be interpreted as a 0.34%p and 0.26%p increase in residential electricity consumption as a result of a 1%p increase in P65 and P6579, respectively. However, another dependency ratio of those aged over 80 to those of prime age, P80, shows statistically insignificant estimates. Therefore, we can infer that people aged 65 and over in Korea generally have higher residential electricity usage. However, when we divide the old age group more specifically, it is hard to conclude that people aged 80 and over have no effect on the residential electricity demand.

Next, we discuss the control variables. The estimated coefficient of the income variable, Y , is 0.26 to 0.36, and is statistically significant under the 1% level for all the models. The estimated coefficient, interpreted as the marginal effect of income on electricity demand, indicates that a 1%p increase in income leads to a 0.26 to 0.36%p increase in residential electricity demand. The residential electricity price, RP , shows negative estimates of −0.11 and −0.14 in Model 1 and Model 5, and is statistically significant under the 5% level. The oil price, OP , as the general fossil fuel price, shows a positive sign and is statistically significant under the 1% level in Models 1, 3 and 5. In Models 2, 4 and 6, representing the own-price variable to cross-price variable, the sign of the electricity variable becomes negative under the 1% significance level. These overall effects of price variables support economic theory, thus we conclude that the models are well constructed. The estimated coefficients of HDD and CDD have similar magnitudes of around 0.03 to 0.05, which are positive and significant at least under the 10% level.

4.3. Robustness

This section considers robustness checks. We consider robustness to alternative population age structure variables. In previous empirical analysis, we include P0014, P65, P6579 and P80 to represent the age structure. All of these three variables are divided by the prime age group in order to capture the relative effects. However, according to a few existing studies, we use more direct age structure variables as alternatives [13,19,29]. A0014 refers to the share in the total population of the youth aged between 0 to 14 years; O65, O6579 and O80 are the share of the population aged 65 and over, 65 to 80 and 80 and over, respectively.

We use the same procedure of panel unit-root and cointegration tests, and we can conclude that there is a long-run equilibrium relationship among existing and newly introduced age structure variables (Unit-root and cointegration tests results can be provided upon request). The robustness of the long-run and short-run coefficients is summarized in Table 9; Table 10.

Table 9. Robustness of long-run coefficient estimates.

Var	Group 1	Group 2	Group 3
A0014 _{it}	1.23 ***	1.25 ***	1.32 ***
O65 _{it}	0.36 ***		
O6579 _{it}		0.28 ***	
O80 _{it}			0.09
RP _{it}	−0.59 ***	−0.55 ***	−0.61 ***
OP _{it}	0.05	0.08	0.08
Y _{it}	0.28 ***	0.22 ***	0.48 ***

Notes: *** Significance at 1%.

Table 10. Robustness of short-run coefficient estimates.

Var	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10
$\Delta A0014_{it}$	0.96 ***	0.96 ***	1.03 ***	1.04 ***	1.05 ***	1.05 ***
$\Delta O65_{it}$	0.28 **	0.28 **				
$\Delta O6579_{it}$			0.18 **	0.18 **		
$\Delta O80_{it}$					0.08 *	0.08 *
ΔY_{it}	0.27 ***	0.27 ***	0.27 ***	0.26 ***	0.32 ***	0.32 ***
ΔRP_{it}	−0.09 *		−0.12 ***		−0.09 **	
ΔOP_{it}	0.08 ***		0.08 ***		0.09 ***	
$\Delta (RP_{it}/OP_{it})$		−0.08 ***		−0.09 ***		−0.09 ***
ΔHDD_{it}	0.03 *	0.03 *	0.04 **	0.04 **	0.04 *	0.04 *
ΔCDD_{it}	0.05 ***	0.05 ***	0.05 ***	0.05 ***	0.05 ***	0.05 ***
ECT _{it-1}	−0.48 ***	−0.48 ***	−0.48 ***	−0.48 ***	−0.50 ***	−0.50 ***
Adj-R ²	0.60	0.61	0.59	0.59	0.60	0.60

Notes: * Significance at 10%, ** significance at 5%, *** significance at 1%.

The results are qualitatively the same as the previous estimation in Sections 4.1 and 4.2 in which we conclude that the population age structure effect is robust for residential electricity consumption. Even so, we can find statistical improvements in Table 10. The adjusted-R² in Models 5 to 10 is about 0.60, which is a slight improvement over the previous value of 0.57 in Models 1 to 6. Further, O80, the share of people aged 80 and over, is statistically significant under the 10% level, whereas in Models 5 and 6, the coefficients of P80 are not statistically significant. Thus, we may address that people aged 80 and over may weakly raise residential electricity consumption in the short-run in terms of statistical significance, but its magnitude is smaller than for people aged 65 and over.

5. Conclusions and Policy Implications

Korea has been facing critical demographic issues with regard to population aging. In addition, a growing trend towards sustainable growth sheds light on the energy policy in Korea. In the present

study, we analyze the effects of the population age structure on the residential electricity demand by using Korean panel data at the regional level. Our empirical analysis has shown clear evidence of age structure effects on residential electricity consumption that would provide important economic implications for energy and industrial policy.

When it comes to the population age structure's effects, we find that an increase in both the youth dependency ratio and the old age dependency ratio, over 65 to prime, lead to an increase in residential electricity consumption in the short- and long-run. We further divide the group of people aged 65 and over into two groups, those aged 65 to 79 and 80 and over, to investigate the heterogeneous age structure effect. We also find a positive impact of people aged between 65 and 79 to prime on the residential electricity demand. On the other hand, an increase in the old age dependency ratio, over 80 to prime age, generally has no effect on residential electricity consumption.

We can conclude that people aged 65 and over in Korea generally use more electricity when compared to the prime age population, despite a heterogeneous effect from different old age groups, because old people tend to stay home longer and are concerned more about heating and cooling to maintain their health.

The results documented in this paper have important policy implications. Korea declared that it will reduce its greenhouse gases (GHGs) by 37% from the business as usual levels by 2030. The growth of the residential electricity demand is accelerated by the youth and old population with the growth in heating and cooling demands, and this would be a barrier for the NDC goal (Pezzutto et al. [52] find that energy consumption for air conditioning steadily increases over the past two decades in Europe. And they expect positive growth in space cooling market due to the increase in comfort requests by the European population concerning climatic well-being in dwellings and workplaces). Statistics Korea, the Korean statistics authority, predicts that the share of old people will be continuously increasing, reaching 24.5% in 2030 and 32.8% in 2040 [1]. Based on our empirical results, this trend could raise the residential electricity consumption with corresponding negative effects on GHGs. Demographic factors might be considered in forecasting future economic activities for calculating the NDC goal; however, the behavioral pattern of the aged population should be also considered for future energy policies.

Significantly increasing the supply of electricity from renewable sources could be a major solution in the era of an aging society. The Korean government aims to enhance renewable energy towards the year 2030 through the recently established National Renewable Energy Plan. However, the pace of renewable energy deployment in Korea is quite slow. The BP Statistical Review of World Energy 2017 reports that installed photovoltaic (PV) power and wind turbine cumulatively provide 4350 MW and 1089 MW respectively in Korea [53]. These capacities are far behind those of Japan and most advanced European countries. The World Development Indicator also shows that only 1% of electricity production is from renewable sources, excluding hydroelectric [54].

Additionally, energy efficiency improvement policies, such as weatherization programs, seem to be appropriate policies for the older generation to reduce electricity consumption in Korea, since enhancing the renewable energy capacity may not be implemented in the short-run [55]. The OECD report states that the old-age income poverty of Korea reached 45.7% in the latest statistics, which is the highest level among OECD countries [56]. Considering that the average old-age income poverty rate in OECD countries is 12.5%, the value is about three times higher. Furthermore, the old generation only earns 69% of the average income in Korea, which is a very low value compared to 87.6%, the average of OECD members [56]. This old-age income poverty could be a liquidity constraint for switching the existing facilities to more efficient ones. Considering that one of the prominent reasons that old people consume more electricity is heating and cooling for their health, supporting such energy efficiency improvements could help reduce domestic energy consumption. Local governments have been supporting the improvement of energy efficiency, but nation-wide and more sophisticated policies will be needed to address the energy efficiency improvement for old people.

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