Korea and the World Economy, Vol. 22, No. 1 (April 2021) 63-79

Aggregate Energy Demand in Korea: An Empirical Model with Total Factor Productivity*

Sukha Shin**, Hanwook Yoo***

This study examines the relationship among energy demand, GDP, real energy price, and total factor productivity in Korea. Total factor productivity is introduced into the model as a proxy variable for technical change, which helps to identify correctly the long-run relationship. This study employs various cointegration tests and estimation methods, yielding robust evidence of a cointegrating relationship and reliable estimates of the parameters. The estimated error correction model forecasts that the growth of energy demand in Korea will slow down as economic growth depends more on total factor productivity than in the past.

JEL Classification: C51, C53, Q41, Q43
Keywords: energy demand, total factor productivity, cointegration, error correction, Korea

---

* Received February 15, 2021. Accepted March 17, 2021. This paper is based on a research project (#2017 Improving the National GHG Emissions Projection Model) of the Greenhouse Gas Inventory and Research Center. The authors are grateful to two anonymous referees for their helpful comments.
** First author, Associate professor, Department of economics, Sookmyung Women's University, E-mail: shin89kr@sm.ac.kr
*** Corresponding Author, Associate professor, Department of economics, Hallym University, E-mail: hanwook67@hallym.ac.kr

1. INTRODUCTION

Given the importance of global climate change mitigation, it has never been before so crucial that policymakers understand the determinants of energy demand. To establish appropriate energy policy, they need reliable models which provide reasonable forecasts of energy demand.

Most of the earlier models of energy demand focus on inter-fuel substitution as a way to minimize costs, following the seminal study of Berndt and Wood (1975). Although these models are useful when analyzing the demand of a particular energy source, they do not guarantee consistency between macroeconomic variables and aggregate energy demand as the sum of the demands of individual energy sources.

Several studies have addressed directly the relation between aggregate energy demand and macroeconomic variables (e.g., Beenstock and Wilcoks, 1981; Welsh, 1989; Hunt *et al*., 2003). These studies have often used a single equation approach. Despite of some criticism such as ad hoc specification and lack of optimization behavior, this approach has become widely used because it requires less data, the results are straightforward to interpret, and there is consistency between aggregate energy demand and macroeconomic variables.

The primary goal of these studies has been to obtain "better estimates of the price and income elasticities needed for forecasting and policy analysis" as Jones (1994) emphasizes. However, it seems that there is a fairly wide range of estimates in the literature, especially for the price elasticity. Adeyemi and Hunt (2007) review some previous studies and show that the estimates of price elasticity vary from –0.5 to 0.1 for OECD countries.

To explain why the estimates of price elasticity of energy demand is so unstable, many studies have considered the effect of technical change. It is plausible that consumers react differently to price change, depending on the cost of available energy-saving technology. Beenstock and Wilcocks (1981) include a simple deterministic time trend in their energy demand model to capture the technical change. In the case of a panel data, Griffin and

Schulman (2005) included exogenous time dummies to account for technical changes in their models.

Against this approach of exogenous technical change, Kouris (1983) argued that technical change should be endogenous in a model because it is in general induced by price. Gately and Huntington (2002) suggest a way of estimating energy demand by allowing asymmetric price responses (APR), following the argument of Dargay and Gately (1995) that high energy prices seem to have a lasting effect on demand. Griffin and Schulman (2005) regard the APR as a proxy for energy-saving technology. Later, Adofo *et al.* (2013) point out that the estimates using the APR are sensitive to sample period used for the estimation.

Another way of handling technical change is suggested by Hunt *et al.* (2003). They insist that a flexible stochastic trend should be incorporated in energy demand model to account for not only technical change but also other important socio-economic effects. They call this stochastic trend 'the underlying energy demand trend (UEDT)' and show that it can be estimated by Harvey (1989)'s structural time series method.

It seems that there is no consensus yet on what is the most appropriate way to capture technical change when modeling energy demand for a particular country. By conducting a testing procedure for the APR and UEDT in energy demand models for 17 OECD countries, Adeyemi *et al.* (2010) find that the UEDT dominates APR for 9 countries whereas the APR and UEDT appear to be substitutes or compliments for the other countries.

This study proposes an alternative way to capture technical change in modeling aggregate energy demand for Korea. It is shown that the empirical results can be improved by adding total factor productivity (TFP) as a proxy variable of technical change into the model. Total factor productivity is the portion of output that cannot be explained by the accumulation of inputs such as labor and capital. As TFP is measured as residuals by subtracting the contributions of labor and capital from GDP, it can include anything else but labor and capital. TFP is used as a popular measure of economic efficiency of an economy. If we search for a variable that represents both technical change and socio-economic factors, TFP should be considered as the most suitable candidate.

In addition to its practical usefulness of simplicity, introducing TFP in the model helps to explain a slow-down of energy demand growth. Energy demand grows as income grows, but usually at a decreasing rate as income reaches higher levels, owing to the development of energy-saving technology or the conversion to a less energy-intensive industrial structure. As we will see later, this feature is important in the context of forecasting.

Another distinguishable feature of this study is that various tests and estimation methods are used in order to verify the robustness of the results. Since most macroeconomic variables are most likely to be nonstationary, the cointegration, or error correction method is used. It is well known that most cointegration tests have problems of size distortion or low power in a small sample (Maddala and Kim, 1998). Hence, it is quite common to have contradictions in the test results for cointegration.

Some previous studies, such as Bae (2016) and Oh and Lee (2003), have found a cointegrating relationship among energy demand, income and energy price in Korea. However, these results are based on one testing method, Johansen (1991), only and the robustness of the cointegration has not been examined. We will show that the cointegrating relationship between energy demand, GDP, and energy price in Korea becomes robust when TFP is included in the relationship.

The data and methodology are discussed in the next section, followed by a presentation of the empirical results. The final section concludes the paper.

2. DATA AND METHODOLOGY

A model of aggregate energy demand is specified whereby energy demand depends on income and energy price as follows:

$$\ln e_t = \beta_0 + \beta_1 \ln y_t + \beta_2 \ln p_t + \epsilon_t . \qquad (1)$$

More specifically, e is aggregate energy demand per capita, y is real GDP per capita, p is real energy price, and ϵ is an error term.

One way to consider technical change is simply adding a linear time trend to the equation (1).

$$\ln e_t = \beta_0 + \beta_1 \ln y_t + \beta_2 \ln p_t + \beta_3 trend + \epsilon_t. \tag{1a}$$

Or a more flexible trend such as TFP can be used as follows:

$$\ln e_t = \beta_0 + \beta_1 \ln y_t + \beta_2 \ln p_t + \beta_4 \ln tfp_t + \epsilon_t. \tag{1b}$$

Once the cointegrating coefficients in the equations (1)-(1b) are estimated, an error correction model is estimated in the second step using the ordinary least squares method:

$$\ln \Delta e_t = \gamma_0 + \gamma_1 \ln \Delta y_t + \gamma_2 \ln \Delta p_t + \gamma_3 \ln \Delta tfp_t + \alpha \epsilon_{t-1} + \sum_i \delta_i z_t^i + \nu_t, \tag{2}$$

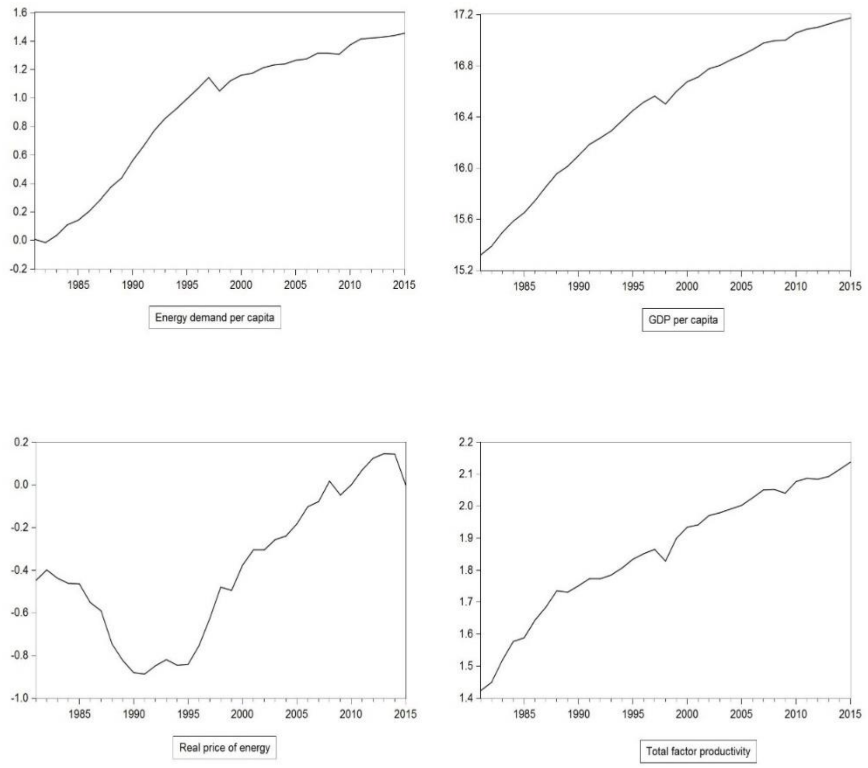
where Δ denotes the first-order difference of a time series; ϵ_{t-1} is an error correction term, obtained from one of the equations (1)-(1b) as the lagged estimated error term; α is the error correction coefficient; z is a stationary variable that affects the short-run fluctuation of the aggregate energy demand; and ν denotes the error. In this study, sectoral energy shares are used for the z-variables.[1)]

The annual data set covers the period 1981-2015. The aggregate energy consumption (measured in kilotons of oil equivalent) is obtained from the database of the Korean Statistical Information Service (KOSIS), and the real GDP (measured in the local currency at 2010 prices) is taken from the database of the Economic Statistics System (ECOS) of the Bank of Korea. Both are converted to per capita terms using population data taken from the KOSIS. The producer price index of the energy component from the ECOS is used for

1) Sectoral energy shares are included to consider different energy demand of various economic activities.

the nominal energy price. To obtain the real energy price, we deflate it by the overall producer price index. The TFP data are based on the growth accounting results of Shin *et al.* (2013).2) The data on the energy shares of end-use sectors, such as industry, transportation, residential and commercial buildings, and public use, are taken from the yearbook of energy statistics. All variables are transformed to logarithm form. Figure 1 presents a time-series plot of the main variables (in logarithm form).

Figure 1 A Time-series Plot of the Main Variables (in Logarithm Form)



2) TFP data are extended for 2013-2015 using the growth accounting method of Shin *et al.* (2013). As a referee points out, TFP data can differ by the details of the growth accounting method. For robustness check, it is necessary to examine alternative measures for TFP.

For the unit root tests, this study employs the ADF-GLS test and the point-optimal test of Elliott *et al.* (1996), as well as tests suggested by Phillips and Perron (1988), Ng and Perron (2001), and Kwiatkowski *et al.* (1992; KPSS hereafter). All the tests have a null hypothesis of a unit root, except KPSS test, which has a null hypothesis of stationarity. When necessary, the maximum lag length is set to four, and the Akaike information criterion is applied to choose the optimal lag length. In the estimation of the long-run covariance matrix, the quadratic-spectral kernel is used with the automatic bandwidth of Newey and West (1994). All the variables are assumed to have a deterministic linear time trend.

Various cointegration tests are employed, including those of Engle and Granger (1987), Phillips and Ouliaris (1990), Hansen (1992), Park (1990), and Johansen (1991). Among these tests, those of Engle and Granger (1987) and Phillips and Ouliaris (1990) have a null hypothesis of no cointegration, while Hansen (1992) and Park (1990) have a null hypothesis of cointegration. Johansen (1991) tests a null hypothesis of at most r cointegrating vectors among the variables, against an alternative hypothesis of $r+1$ cointegrating vectors.

In order to estimate the cointegrating coefficients in equation (1)-(1b), this study uses the method of Johansen (1991), the fully modified least squares(FM-OLS) method of Phillips and Hansen (1990), and the dynamic OLS (DOLS) of Stock and Watson (1993).

3. EMPIRICAL RESULTS

As shown in Table 1, all the variables in equation (1)-(1b) have a unit root. The null hypothesis of stationarity of the KPSS test is rejected at the 5% significance level, while the null hypotheses of unit roots in the other tests are not rejected.

Table 1 Unit Root Tests

	Test statistic	e	y	p	tfp
Elliott *et al*. (1996)	ADF-GLS	–1.71	–0.57	–2.09	–1.74
	Point Optimal	58.54	102.54	21.20	20.25
Phillips and Perron (1988)		–0.45	0.19	–1.56	–1.75
Ng and Perron (2001)	MZ_{α}^{GLS}	–0.76	0.37	–4.41	–5.22
	MZ_{t}^{GLS}	–0.40	0.23	–1.48	–1.52
	MSB^{GLS}	0.53	0.64	0.34	0.29
	MP_{T}^{GLS}	59.16	93.49	20.67	17.06
KPSS		0.17^{**}	0.19^{**}	0.15^{**}	0.16^{**}

Notes: 1) The superscripts ***, **, and * next to the numbers represent significance at the 1%, 5%, and 10% levels, respectively.
2) The null hypothesis of the KPSS test is stationarity, while those of the other tests are a unit root.

The cointegration test results are reported in table 2. When the cointegrating relationship between energy demand, GDP, and energy price without considering technical change as in eq. (1) is tested, only the test of Park (1990) supports the cointegrating relationship. The null hypothesis of no cointegration of both Engle and Granger (1987) and Phillips and Ouliaris(1990) are not rejected, while the null hypotheses of cointegration of Hansen(1992) is rejected at the 1% significance level. Although the test results of Johansen (1991) suggest three cointegrating vectors, these results do not conform with the unit root test results because three cointegrating vectors imply stationarity of energy demand, GDP, and energy price.

When we include a linear trend in the model like eq. (1a), the tests of Johansen (1991) join to Park (1990) in supporting the cointegrating relationship. Still the other tests remain against the cointegrating relationship. In contrast, when TFP is included as in eq. (1b), the cointegrating relationship is supported by all the tests. The null hypotheses of no cointegration of both Engle and Granger (1987) and Phillips and Ouliaris (1990) are rejected at the 5% significance level, while the null hypotheses of cointegration of Hansen (1992) and Park (1990) are not rejected. The tests of Johansen (1991) also support the existence of cointegration among the variables. For both the trace

Table 2 Cointegration Tests

Test	Null hypothesis	Eq. (1) e, y, p constant	Eq. (1a) e, y, p linear trend	Eq. (1b) e, y, p tfp
Engel and Grange (1987)	No cointegration	–2.16	–3.58	–4.50**
Phillips and Ouliaris(1990)	No cointegration	–2.80	–3.06	–4.65**
Hansen (1992)	Cointegration	1.18***	1.26***	0.27
Park (1990)	Cointegration	0.00	1.07	0.01
Johansen (1991) λ_{trace}	Number of cointegrating vectors	3	2	1
λ_{max}		3	1	1

Note: The superscripts ***, **, and * next to the numbers represent significance at the 1%, 5%, and 10% levels, respectively.

statistic and the λ_{max} statistic, the null hypothesis of no cointegration are rejected at the 5% significance level, whereas the null hypothesis of at most one cointegrating vector cannot be rejected at the 5% significance level. In summary, the evidence of cointegration is fairly robust when TFP is included in the model. All the tests considered here support the existence of a cointegrating relation between energy demand, GDP, real energy price, and TFP.

Table 3 Cointegrating Vectors

		Eq. (1a)			Eq.(1b)	
	FM-OLS	DOLS	Johansen	FM-OLS	DOLS	Johansen
Income (β_1)	0.95 (0.20)	0.78 (0.17)	0.43 (0.13)	1.80 (0.08)	1.46 (0.15)	1.32 (0.26)
Price (β_2)	-0.12 (0.02)	-0.26 (0.07)	-0.51 (0.07)	-0.15 (0.02)	-0.18 (0.02)	-0.25 (0.05)
Trend (β_3)	0.00 (0.01)	0.01 (0.01)	0.03 (0.01)			
Productivity (β_4)				-2.49 (0.22	-1.60 (0.43)	-0.68 (0.74)

Note: The numbers in parentheses are standard errors.

Furthermore, when TFP is included in the model, the estimates of price elasticity and income elasticity become more stable. As shown in table 3, the estimate of income elasticity varies from 1.32 to 1.80 when TFP is used whereas it lies in the range of 0.43-0.95 for the model with a linear trend. Similarly, the range of the estimated price elasticity is narrower for the model using TFP from –0.15 to –0.25 than that of the model using a linear trend from –0.12 to –0.51.

The price elasticity of –0.2 from the model using TFP also conform relatively well with that of previous studies. For instance, Bae (2016) and Hunt and Manning (1989) report price elasticity of –0.3 for Korea[3] and UK respectively, and Hunt and Ninomiya (2005) finds a long-run price elasticity of about –0.2 for Japan.[4] On the other hand, the income elasticity of 1.5 is seemingly somewhat greater than the value of 1.1 in Bae (2016) and Hunt and Ninomiya (2005), and significantly higher than the value of 0.5 in Hunt and Manning (1989). Here, it was necessary to take into account the effect of TFP and the difference in the industrial structure between Korea and the UK. In the context of a production function, TFP is one of the factors that produces the GDP and, thus, GDP growth usually includes an improvement in TFP. In this study, GDP represents the effect of income on energy after controlling the effect of TFP. Shin (2014) estimated the contribution of TFP to GDP growth in Korea for the period 1981–2010 as approximately 30%. Thus, the income elasticity combined with the negative effect of TFP, was calculated to be about 1.0, which is close to the value of 1.1 in Bae (2016) and Hunt and Ninomiya (2005). Furthermore, considering the more energy-intensive industrial structure of Korea, it is understandable that Korea has a greater income elasticity than that of the UK.

---

[3] Bae (2016) employed a nominal energy price, following Asafu-Adjaye (2000) who use a consumer price index in estimating energy demand functions for Asian developing countries. Oh and Lee (2003) does not report the elasticities because they are not interested in estimating the elasticities but testing the causal relationship between energy consumption and economic growth.

[4] The estimate of price elasticity of Hunt and Ninomiya (2005) is obtained from the model with the UEDT.

Table 4 Error Correction Model

	Model using a linear trend Eq. (1a) + Eq. (2)	Model using TFP Eq, (1b) + Eq. (2)
Income (γ_1)	0.89 (0.10)***	1.09 (0.19)***
Productivity (γ_3)		–0.44 (0.24)*
Error correction (α)	–0.42 (0.06)**	–0.71 (0.08)**
Industry (δ_{ind})	4.22 (1.24)***	3.63 (0.97)***
Residential & commercial ($\delta_{R\&C}$)	4.62 (1.37)***	3.79 (1.06)***
Transportation (δ_{tra})	3.94 (1.07)***	3.09 (0.82)***
Adj-R^2	0.88	0.91

Note: The superscripts ***, **, and * represent significance at the 1%, 5%, and 10% levels, respectively.

To utilize the short-run dynamics, the error correction model given in eq. (2) is estimated using the estimated lagged error term from the DOLS estimates of the equation (1a) and (1b) respectively.[5] As presented in table 4, contemporaneous terms for the first-differenced variables are included after various lagged variables are examined. Energy price was not statistically significant in both models, suggesting that an adjustment in energy demand to a change in price may take time and, thus, energy price matters only in the long run. The short-run effect of income is greater than that of TFP, implying that energy demand in the short run is more sensitive to a change in income than it is to a change in technology or institution.

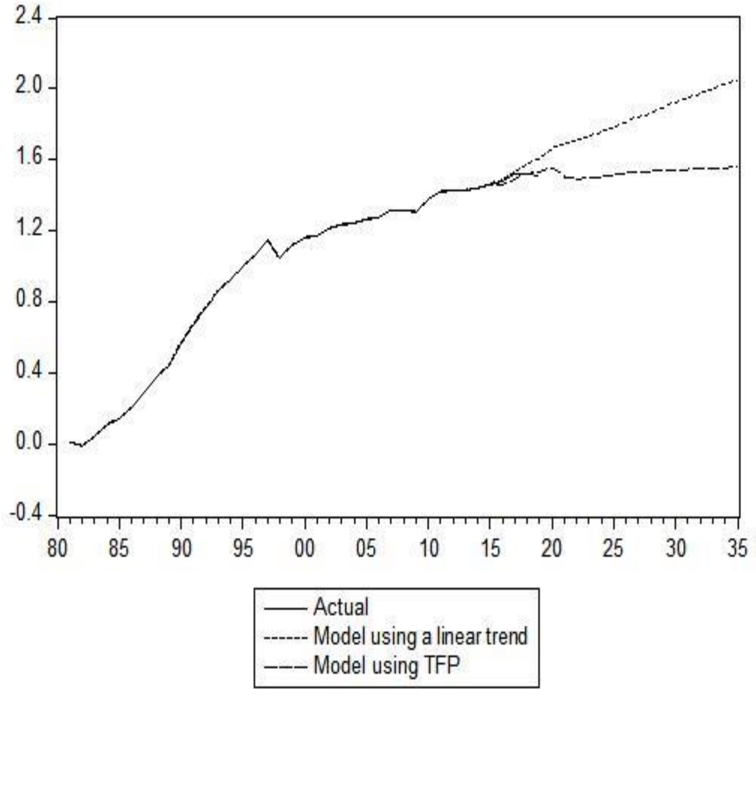
The coefficient for the error correction term is estimated to be about –0.7 for the model with TFP, suggesting that 70% of any deviation from the long-run equilibrium was adjusted each year. The adjustment speed of the model with a linear trend appears to be lower, around –0.4. It may be another evidence that the cointegrating relationship is relatively unstable in the model with a linear trend. Interestingly, the adjustment speed of –0.7 was close to

[5] We took the estimates from the DOLS method because they seem to lie between those of FM-OLS and Johansen.

the value of –0.67 of Hunt and Manning (1989) and –0.65 of Hunt and Witt (1995).

Changes in the sectoral composition of energy demand have significant effects in the short run. Since a constant and sectoral energy shares are included in the regression equation, the energy share of the public sector is excluded to avoid perfect multi-collinearity. Thus, the estimated coefficient of the sectoral energy share should be interpreted in relative terms to the public sector. The estimation results suggest that energy demand grows faster when the energy share shifts from the public sector to the other sectors, and that the residential and commercial sectors contribute most to the growth of energy demand.

Figure 2 Actual, Fitted, and Forecasted Energy Demand Per Capita (in logarithm form)



Finally, the forecast of energy demand is obtained from the error correction models in table 4. The assumptions for the GDP, energy price, and sectoral shares of energy are taken from the Second National Energy Master Plan of the Korean government for the period 2013-2035, and the assumptions for TFP are taken from Shin *et al*. (2013).

As shown in figure 2, when the model with a linear trend is used, the energy demand per capita in Korea is forecasted to grow at the almost same speed as in the past. This is similar to the forecasts of Bae (2016). In contrast, when the energy-saving effect of TFP growth is considered, the energy demand per capita in Korea is forecasted to grow at a slower rate than it has in the past. The Korean economy has depended heavily on labor and capital. However, it is expected to rely more on TFP in future, which will slow down the growth of energy demand. Indeed, for the period 2016-2019, the energy consumption growth has stagnated in Korea. The actual data stay closer to the forecasts of the model using TFP.

4. CONCLUSION

This study examined the relationship between energy demand per capita, GDP per capita, real energy price, and TFP in Korea using annual time series data for the period 1981 to 2015. Only when TFP was included in the relation, the testing results provided relatively robust evidence of a long-run cointegrating relationship and the estimation results appeared to lie in a narrower range.

The estimation results of the error correction model showed a statistically significant negative parameter for the error correction term. In addition, there was evidence of an income effect in the short run, but no such evidence of a price effect. This implies that the effectiveness of policies that aim to diminish energy consumption via the energy price will be limited, at least in the short run. The error correction model provides reasonable forecasts of energy demand, the growth of which will slow due to a greater reliance of economic growth on TFP.

Lastly, note that although the approach of this study has some advantages, it has exposed weakness that need further research, such as omitted determinants from the specification and measurement error of TFP. It is uncertain if this approach will work for other countries. Also it has not been examined whether the use of TFP outperforms the APR or UEDT and whether they are substitutes or compliments. As a referee suggests, it is worth to seek a better proxy for energy saving technology than TFP, such as R&D.

REFERENCES

Adeyemi, O. I., D. C. Broadstock, M. Chitnis, L. C. Hunt, and G. Judge, "Asymmetric Price Responses and the Underlying Energy Demand Trend: Are They Substitutes or Complements? Evidence from Modelling OECD Aggregate Energy Demand," *Energy Economics*, 32(5), 2010, 1157-1164.

Adeyemi, O. I. and L. C. Hunt, "Modelling OECD Industrial Energy Demand: Asymmetric Price Responses and Energy-saving Technical Change," *Energy Economics*, 29(4), 2007, 693-709.

Adofo, Y. O., J. Evans and L. C. Hunt, "How Sensitive to Time Period Sampling is the Asymmetric Price Response Specification in Energy Demand Modelling?" *Energy economics*, 40, 2013, 90-109.

Asafu-Adjaye, J., "The Relationship between Energy Consumption, Energy Prices and Economic Growth: Time Series Evidence from Asian Developing Countries," *Energy Economics*, 22(6), 2000, 615-621.

Bae, Y., "Estimation and Forecast of Long-run Energy Demand Function: A Cointegration Approach," *Korean Energy Economic Review*, 14(2), 2016, 21-50.

Beenstock, M. and P. Willcocks, "Energy Consumption and Economic Activity in Industrialized Countries: The Dynamic Aggregate Time Series

Relationship," *Energy Economics*, 3(4), 1981, 225-232.

Berndt, E. R. and D. O. Wood, "Technology, Prices, and the Derived Demand for Energy," *The Review of Economics and Statistics*, 57(3), 1975, 259-268.

Dargay, J. and D. Gately, "The Imperfect Price Reversibility of Non-transport Oil Demand in the OECD," *Energy Economics*,17(1), 1995, 59-71.

Elliott, G., T. Rothenberg, and J. Stock, "Efficient Tests for an Autoregressive Unit Root," *Econometrica*, 64(4), 1996, 813-836.

Engle, R. F. and C. W. J. Granger, "Cointegration and Error Correction: Representation, Estimation and Testing," *Econometrica*, 55(2), 1987, 251-276.

Gately, D. and H. G. Huntington, "The Asymmetric Effects of Changes in Price and Income on Energy and Oil Demand," *The Energy Journal*, 23(1), 2002, 19-55.

Griffin, J. M. and C. T. Schulman, "Price Asymmetry in Energy Demand Models: A Proxy for Energy-saving Technical Change?" *The Energy Journal*, 26(2), 2005, 1-22.

Hansen, B., "Efficient Estimation and Testing of Cointegrating Vectors in the Presence of Deterministic Trends," *Journal of Econometrics*, 53(1-3), 1992, 87-121.

Harvey, A. C., *Forecasting, structural time series models and the Kalman filter*, Cambridge, UK: Cambridge University Press, 1989.

Hunt, L. C. and R. Witt, "An Analysis of UK Energy Demand Using Multivariate Cointegration," Surrey Energy Economics Discussion Papers No. 86, Surrey: University of Surrey, 1995.

Hunt, L. C. and D. N. Manning, "Energy Price- and Income-elasticities of Demand: Some Estimates for the UK Using Cointegration Procedure," *Scottish Journal of Political Economy*, 36(2), 1989, 183-193.

Hunt, L. C., G. Judge and Y. Ninomiya, "Underlying Trends and Seasonality in UK Energy Demand: A Sectoral Analysis," *Energy Economics,* 25(1), 2003, 93-118.

Hunt, L. C. and Y. Ninomiya, "Primary Energy Demand in Japan: An

Empirical Analysis of Long-term Trends and Future CO2 Emissions," *Energy Policy*, 33(11), 2005, 1409-1424.

Johansen, S., "Estimation and Hypothesis Testing of Cointegration Vectors in Gaussian Vector Autoregressive Models," *Econometrica*, 59(6), 1991, 1551-1580.

Jones, C., "Accounting for Technical Progress in Aggregate Energy Demand," *Energy Economics*, 16(4), 1994, 245-252.

Kouris, G., "Fuel Consumption for Road Transport in the USA," *Energy Economics*, 5(2), 1983, 89-99.

Kwiatkowski, D, P. Phillips, P. Schmidt, and Y. Shin, "Testing the Null Hypothesis of Stationary against the Alternative of a Unit Root," *Journal of Econometrics*, 54(1–3), 1992, 159-178.

Maddala, G. S. and I. Kim, *Unit Roots, Cointegration and Structural Change*, Cambridge, UK: Cambridge University Press, 1998.

Newey, W. and K. West, "Automatic Lag Selection in Covariance Matrix Estimation," *Review of Economic Studies*, 61(4), 1994, 631-653.

Ng, S. and P. Perron, "Lag Length Selection and the Construction of Unit Root Tests with Good Size and Power," *Econometrica*, 69(6), 2001, 519-1554.

Oh, W. and K. Lee, "Multivariate Vector Error Correction Approach of Granger Causality between Energy and GDP," *The Korean Journal of Economic Studies*, 51(1), 2003, 257-271.

Park, J., "Testing for Unit Roots and Cointegration by Variable Addition," *Advances in Econometrics*, 8(2), 1990, 107-133.

Phillips, P. and B. Hansen, "Statistical Inference in Instrument Variables Regression with I(1) Processes," *Review of Economic Studies*, 57(1), 1990, 99-125.

Phillips, P. and S. Ouliaris, "Asymptotic Properties of Residual Based Tests for Cointegration," *Econometrica*, 58(1), 1990, 165-193.

Phillips, P. and P. Perron, "Testing for a Unit Root in Time Series Regression," *Biometrika*, 75(2), 1988, 335-346.

Shin, S., "Evaluating TFP Growth of the Korean Economy in 2000s through the Comparison of Growth Accounting Methods," *KDI Journal of Economic Policy*, 36(2), 2014, 137-174.

Shin, S., S. Whang, J. Lee, and S. Kim, *Long-term Forecasts of Main Macroeconomic Indicators of Korea*, Korea Development Institute, 2013.

Stock, J. and M. Watson, "A Simple Estimator of Cointegrating Vectors in Higher Order Integrated Systems," *Econometrica*, 64(4), 1993, 783-820.

Welsch, H., "The Reliability of Aggregate Energy Demand Functions: An Application of Statistical Specification Error Tests," *Energy Economics*, 11(4), 1989, 285-292.