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AN INVESTIGATION INTO THE RELATIONSHIP BETWEEN ENERGY CONSUMPTION AND GDP IN THE OECD COUNTRIES

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Abstract

The study investigated the relationship between energy consumption and GDP in the OECD. Secondary data was used while the Ordinary Least Squares (OLS) method and the Generalized Method of Moments (GMM) estimator were used for our estimation of short-run and long-run elasticities of price and income for total energy and electricity demand for the OECD. The results showed among others that long-run price and income elasticities for total energy are inelastic. Electricity price was found to be inelastic but income elasticity in the electricity model was elastic. The inelastic nature of long-run price and income elasticities of total energy demand shows that energy consumption in the OECD responds slowly to changes in energy price and income. Based on the findings, a recommendation is for policy makers to concentrate on encouraging energy efficiency as a way to reduce energy and electricity consumption.

Keywords: Energy Consumption, GDP, Electricity Demand, income elasticity, Generalized Method of Moments, OECD

INTRODUCTION

Energy enhances the productivity of capital, labour, and other factors of production (Moroney, 1990). This makes it an essential factor for small and large-scale production, residential use and transportation. Technological advancement and technical efficiency in energy use since the start of the industrial revolution has also contributed significantly to an increasing trend in global energy consumption most especially from use of fossil fuels (oil, gas and coal). This development has led policy makers, regulatory bodies and other stakeholders to regard energy as one of the most vital factors in policy formulation, implementation and decision making. In a bid to solve energy-related problems which includes amongst many; security of supply, climate security, energy intensity and price volatility, extensive scholarly researches have been undertaken to develop models and estimation techniques to enable a better understanding of the dynamics in the energy sector.

The unprecedented increase in global energy consumption in past decades cannot be over emphasized. According to BP Statistical Bulletin of world energy 2011, since 1965, global total primary energy consumption has increased by over 200% with the Organization for Economic Cooperation and Development (hereafter, OECD), accounting for approximately close to half of global energy consumption. This is as a result of a 111% increase in OECD primary energy consumption since 1965. Despite improvements in energy efficiency and the implementation of various policies to reduce emission of carbon dioxide (hereafter, CO_2) and other greenhouse gases, OECD has accounted for 46.4% of world primary energy consumption since 2000 (BP Statistical Bulletin, 2011). Total energy price increased by approximately 6% from 1978 to 1979, followed by a significant rise in 1980 by 15%, followed by a 7% and 2% rise in 1981 and 1982 respectively. However, from 1983 to 1989, total energy price fell sharply by 22% followed by a period of fairly stable prices from 1990 to 1999. Similar to electricity prices, an upward trend has also been witnessed in total energy prices since 2000. OECD per capita Gross Domestic Product indicates an upward trend, which suggests increasing economic growth amongst the OECD countries in focus. For instance, from 1978 to 2008, the GDP of the 24 OECD countries investigated in this study rose by 81%.

In line with the above, the following research questions are formulated:

- What is the relationship between energy consumption and GDP in the OECD?
- Are long-run price and income elasticities of total energy demand in the OECD inelastic?
- Are long-run price and income elasticities of electricity demand in the OECD inelastic?

Deriving reliable estimates of price and income elasticities will enable policy makers forecast and make realistic plans for the realization of reduction in energy consumption and increase in energy efficiency. For example, knowing the size of the elasticity of energy price can be used as a yardstick to assess the impact of energy conservation policies and price volatility on energy demand. More so, given the importance of OECD to global energy consumption and emission of CO_2 as stated earlier, the use of the newly developed panel data empirical techniques and an extended data set to estimate OECD demand models will contribute to the existing literature on the subject. Based on the above research questions, this study investigated the relationship between energy consumption and GDP in the OECD and derives the short-run and long-run elasticities of price and income for total energy and electricity demand for the OECD using the Ordinary Least Squares (OLS) method and the Generalized Method of Moments (GMM) estimator. Estimates of short-run price and income elasticities was derived using OLS.

REVIEW OF STUDIES IN ENERGY AND ELECTRICITY DEMAND

Modelling energy demand and other related studies in energy economics became a major area of interest among researchers following the oil price shocks in the 1970s. Given the significance of this subject matter, the development and estimation of different models of energy demand to derive reliable estimates is essential for long term energy planning, forecasting and policy formulation (Hunt and Manning, 1989). Fatai et al. (2003) used the Phillip and Hansen's (1990) FMOLS, Engle-Granger ECM and the ARDL models to estimate and forecast an electricity demand model for New Zealand from 1960 to 1999. They found long-run income and price elasticity of electricity demand to be elastic at (0.81-1.44) and (-0.59 - -0.44) respectively. After using these three techniques, they concluded that the new ARDL approach of Pesaran et al. (1996, 1998) has better forecasting performance than the other approaches considered. Rapanos and Polemis (2006) used the PAM and found residential energy demand for Greece to be price inelastic between 1965 and 1999. Bentzen and Engsted (2001) used cointegration and ECM techniques to estimate a demand relationship for Danish residential energy consumption with special emphasis on the revival of the ARDL model. Residential energy demand for Denmark was found to be income elastic and price inelastic at 1.21 and -0.47 respectively. The ARDL model was also employed by Dergiadis and Tsoulfidis (2008) to estimate residential energy demand in the United States from 1965 to 2006. They preferred the ARDL bounds-testing procedure to the Johansen technique (Johansen, 1988) as it can be applied in cases where the order of integration is mixed. However, they noted that one of the limitations of the ARDL approach to cointegration is that it fails to provide results in the presence of I (2) variables.

Various research studies in energy demand have also focused on the issue of capturing technical progress when modelling energy demand. This is important as energy demand is a derived demand given that it is not demanded for itself but for the services it gives, so the efficiency of appliance stock for example will have a significant impact on energy demand. In line with this, Beenstock and Wilcocks (1981) applied the error correction methodology to estimate the relationship between energy and GDP for developed market economies. In an attempt to capture technical progress, they used a deterministic time trend as proxy to capture the underlying effect of technical progress. However, Kouris (1983) estimated an energy demand relationship for OECD and argued that technological progress is induced by price hence it should be treated endogenously. Kouris (1983) found short run and long run price elasticity of primary energy demand in the OECD to be -0.15 and -0.43 respectively. He however found short-run income elasticity to be elastic at 1.08. In a reply to Kouris (1983), Beenstock and Wilcocks (1983) argued that it is important to attempt to capture exogenous technical progress than simply ignoring it. They however acknowledge that using a deterministic time-trend is not a satisfactory method to capture these effects. Jones (1994) acknowledged that technical progress can be exogenous and/or induced by price changes but argued that it is vital to distinguish between normal price effects which is measured by price elasticity and the exogenous technical progress effect.

In line with the above arguments, Hunt et al. (2000, 2003) argued that it is inappropriate to capture technical progress with a deterministic time trend given that it is likely to grow at variable pace at different times. They introduced the concept of Underlying Energy Demand Trend (hereafter, UEDT) which not only captures technical progress but considers other exogenous non-economic factors that affect energy demand significantly. The UEDT is expected to be positive and /or negative and changing over time; hence the trend is considered to be stochastic rather than deterministic due to increases and decreases in energy efficiency. They estimated the UEDT (*See Hunt et. al (2000, 2003a, 2003b) for a detailed discussion on UEDT. See also Broadstock and Hunt (2010) on further discussions on separating exogenous non-economic factors from UEDT in energy demand modeling*) in a sectoral analysis of UK energy demand using the Structural Time Series Model (STSM) suggested by Harvey (1997). Relating to this research work, Amarawickrama and Hunt (2008) estimated an electricity demand relationship for Sri Lanka using static Engle and Granger method, dynamic Engle and Granger method, FMOLS, Pesaran, Shin and Smith (PSS) method, Johansen method and STSM. They estimated a linear UEDT using the static Engle and Granger method and the FMOLS and also incorporated a stochastic UEDT using STSM to compare results. They found the UEDT to be positive in the static Engle and Granger Method and FMOLS but discovered a negative UEDT in the STSM. They found income to be elastic ranging from 0.99 to 2.96 but found electricity price to be inelastic between 0 and -0.06. This study will however attempt to include a deterministic time trend in its FMOLS estimation to capture exogenous technical progress and other non-economic factors as explained by the UEDT. In related panel surveys, Narayan et. al (2007) used panel unit roots and panel cointegration techniques to estimate short- and long-run income and price elasticities for residential demand for electricity in G7 countries (*USA, Japan, Germany, France, UK, Italy and Canada*) from 1978 to 2003. They discovered that long run residential demand for electricity is price elastic and income inelastic which is contradictory to the findings of Lee and Lee (2010) although the number of countries in the panel set differs significantly.

Using the one-step Generalized Method of Moments (hereafter, GMM) suggested by Arellano and Bond (1991), Liu (2004) specified an ARDL model in the estimation of an energy demand model for energy goods in the OECD from 1978 to 1999. He concluded that demand for electricity, natural gas and oil is price elastic while income elasticity is inelastic in the residential sector of the OECD. The use of the GMM estimator used by Liu (2004) and a number of other studies reviewed in section 2.5 of this literature review arose from the problems of serial correlation between regressors and error terms that the conventional OLS fails to detect when working with dynamic panel relationships. This has however made the use of the GMM estimator become popular in dynamic panel data empirical studies.

Lee and Lee (2010) applied panel unit roots tests, panel cointegration, FMOLS and ECM to estimate the total energy and electricity demand functions for 25 OECD countries between 1978 and 2004. The panel results indicate that total energy demand is income and price inelastic, whereas electricity demand is income elastic and price inelastic. The work of Lee and Lee (2010) is of interest to this research work as it employs a spectrum of robust econometric techniques to derive long-run price and income elasticities of demand for the OECD. Based on this, this study will build upon the methodology of Lee and Lee (2010) in deriving short- and long-run price and income elasticity of demand for 24 OECD countries from 1978 to 2008. As explained earlier, the approach of Amarawickrama and Hunt (2008) in estimating a deterministic UEDT will also be considered in the FMOLS estimation to examine its effect on the elasticities and also examine the trend of energy efficiency or intensity for the OECD (*Energy intensity is the amount of energy used to produce one unit of GDP. If it is high for an economy, it can be assumed that the economy is an energy-using one*). Table 1 presents an overview of results in energy demand studies individual OECD countries and the OECD as a group to have an idea of estimated elasticities in this area considering different empirical techniques. Although this tabulated overview does not fully capture the extensive studies in energy demand modelling relating to this area of research, the criteria for selection is based on related empirical techniques in energy demand (including the ones explained and some not explained) and studies in energy and electricity demand similar to the OECD.

Table 1: Selected Previous Studies in Energy and Electricity Demand

Authors	Data Type	Methodology	Subject	Period	Income Elasticity	Price Elasticity
Beenstock and Wilcocks (1981)	Time-series	ECM aggregate time- series model	OECD	1950-1970	LR: 1.78	LR: -0.06
Kouris (1983b)	Time-series	Aggregate time-series model	OECD	1961-1981	LR: R	LR: -0.43
Prosser (1985)	Time-series	Koyck- lag model	OECD	1960-1982	LR: 1.02	SR: -0.22 LR: -0.40
Li and Maddala(1999)	Time-series	Bootstrap variance estimation	United States	1970-1990	0.38~1.18	-0.08~-0.48
Bentzen and Engsted(2001)	Time-series	ARDL approach	Denmark	1948-1990	SR: 0.67 LR: 1.21	SR: -0.14 LR: -0.47
Fatai et al. (2003)	Time-series	ECM, FMLS and ARDL model	New Zealand	1960-1999	SR:0.24~0.46 LR:0.81~1.44	SR: -0.24~0.18 LR: -0.59 ~-0.44
Narayan and Smyth (2005)	Time-series	Bounds testing procedure	Australia	1969-2000	SR:0.01~0.04 LR: 0.32~0.41	SR: -0.27~-0.26 LR: -0.47~0.54
Galindo (2005)	Time-series	Johansen Procedure	Mexico	1965-2001	0.45~0.64	-0.43~-0.07
Hunt and Ninomiya (2005)	Time-series	ARDL model /STSM	Japan	1887-2001	LR: 1.06	LR: -0.2
Rapanos and Polemis (2006)	Time-series	PAM	Greece	1965-1999	SR: 0.79 LR: 1.54	SR: -0.31 LR: -0.60
Pindyck (1979)	Panel data	Iterative zelnner estimation	OECD	1959-1973	0.7~0.8	RS: -1.25 IS: -1.17~-0.22
Maddala et al. (1997)	Panel data	Shrinkage estimators	United states, 49 states	1970-1990	SR: 0.39 LR: 0.89	SR: -0.16 LR: -0.26
Gately and Huntington (2002)	Panel data	Koyck-lag model, ECM	OECD	1971-1997	LR: 0.58	LR: -0.24
Medlock III and Soligo (2003)	Panel data	2SLS approach	28 OECD/ non-OECD countries	1978-1995	LR: 3.9	LR: -0.3
Liu (2004)	Panel data	Dynamic panel model and GMM	23 OECD	1978-1999	SR: -0.08~1.15 LR: -0.26~4.20	SR: -0.17~0.16 LR: -0.52~0.52
Griffin and Schulman (2005)	Panel data	Koyck-lag model	OECD	1961-1996	LR: 0.41	LR: -0.04
Lee and Chiu (2011)	Panel data	PSTR model	24 OECD	1978-2004	LR: 1.69	LR: -0.23

Sources: Lee and Lee (2010), Al-Rabbaie and Hunt (2006) and updated by Authors

Notes: PSTR: Panel smooth transition regression model, PAM: partial adjustment mechanism, ARDL: autoregressive distributed lag, VAR: vector autoregressive model, 2SLS: two stage least squares, ECM: error correction model, GMM: generalized method of moments, FMLS: fully modified least squares: LR: long-run, SR: short-run; R: restricted

RESEARCH METHODOLOGY

Model Specification

The study adapts the methodology of Al-Iriani (2006) in the panel VECM estimation as well as those of Lee and Lee (2010). This methodology follows the specification of two log-linear models of total energy and electricity demand:

Total Energy Demand Model: $TEC_{it} = \alpha_i + \beta_i\, GDP_{it} + \gamma_i TEP_{it} + \varepsilon_{it}$ (1)

Electricity Demand Model: $EPC_{it} = \alpha_i + \varphi_i\, GDP_{it} + \theta_i REP_{it} + \eta_{it}$ (2)

Where:

TEC represents total energy consumption per capita,

GDP represents gross domestic product per capita (PPP),

TEP represents total energy price,

EPC represents electricity consumption per capita,

REP represents electricity price.

β and γ both represent income and price elasticities in the total energy demand model

φ and θ represent income and price elasticities in the electricity demand model.

ε and η are stochastic error terms,

i represents annual cross sectional observations of the OECD countries (1, 2, 3, ... N) and

t is the time period of the individual cross sectional observations.

Note that all variables are in natural logarithms and the log-linear specification is to derive constant elasticities and reduce heteroscedasticity.

Estimation Issues

Unit Root

The study started by testing for unit root using the IPS, Fisher-ADF and Fisher PP tests. This was based on the autoregressive model: $y_{it} = \rho_i y_{it-1} + \delta_i X_{it} + \mu_{it}$ (3)

Where:

y_{it} is a variable being examined, *i*= 1, 2 ... N is the number of cross-section units and *t*=1, 2...

T_i represents the observed time periods.

X_{it} represents exogenous variables in the model including any fixed and individual trend,

ρ_i represents the autoregressive coefficients and

μ_{it} is a stochastic error term.

When the test is carried out and ρ_i is greater than 1 (ρ_i>1), then y_{it} is said to be weakly trend stationary. However, if ρ_i=1, then there is presence of unit root in variable y_{it}.

The null hypothesis in all the unit root tests assume non-stationarity in the series and the test statistic based on the heteroscedastic Z-statistic which assume stationarity under the null hypothesis.

Panel Cointegration Tests

According to Granger (1981), when series become stationary after being differenced once, the linear combination of these I (1) variables are stationary without differencing; such variables are said to be cointegrated (Al-Iriani, 2006). Pedroni (2004) showed how panel cointegration tests can be carried out allowing for heterogeneity in the intercepts and slopes of the cointegrating equation:

$$y_{it} = \alpha_i + \delta_i t + X_{it}\beta_i + \varepsilon_{it} \qquad (4)$$

Where; y_{it} is a scalar and X_{it} is a (1xm) vector of variables, ε_{it} is an error term and δ_i is a country specific deterministic trend effect. The deterministic trend effect is suggested by (Kim et al, 2005) to capture disturbances that are simultaneous across different countries in the panel. The idea behind this model specification by Pedroni (2004) is to allow for heterogeneity across countries including the long run cointegrating vectors since the parameter estimates are not expected to be the same across all cross-sectional observations. As part of one of the three tests to be carried out, this study will therefore employ the heterogeneous panel cointegration tests introduced by Pedroni (2000) to test if the variables have a long-run relationship.

The two tests introduced by Pedroni (2004) are the within-dimension and the between-dimension panel cointegration tests. The former is made up of four statistics including: panel v-statistic, panel r- statistic, panel PP-statistic and panel ADF-statistic while the latter is made up of three statistics including group r-statistic, group PP-statistic and the group ADF-statistic. The within-dimension tests work by pooling the data across the within-dimension. It accounts for common time factors and heterogeneity across members of the panel. The between-dimension tests allow for parameter heterogeneity across members regarded as group mean cointegration statistics. All these statistics follow a standard normal distribution in large samples.

For thorough empirical investigation, this study also used the Kao (1999) panel cointegration test and the non-parametric Johansen Fisher panel cointegration test which is based on the aggregation of the p-values of the individual Johansen maximum likelihood cointegration test statistics. The Kao (1999) test does not allow for heterogeneity among the individual units of the panel and it specifies cross-section specific intercept and homogeneous coefficients on the first stage regressors. The test statistic of the Fisher test does not assume homogeneity in the coefficients of the different countries (Lee and Lee 2010).

In line with these points, the Pedroni (2004) and Johansen Fisher cointegration tests was carried out with and without a deterministic trend for the two demand relationships specified in equations 6 through 8, which helped us to examine the effect of the trend on the relationships. However, the Kao (1999) test does not allow for the inclusion of a deterministic time trend. The following equations are specified:

Models of Total Energy

$TEC_{it} = \alpha_i + \beta_i GDP_{it} + \gamma_i TEP_{it} + \varepsilon_{it}$ (without time trend) (5)

$TEC_{it} = \alpha_i + \delta_i t + \beta_i GDP_{it} + \gamma_i TEP_{it} + \varepsilon_{it}$ (with time trend) (6)

Models of Electricity

$EPC_{it} = \alpha_i + \varphi_i GDP_{it} + \theta_i REP_{it} + \varepsilon_{it}$ (without time trend) (7)

$EPC_{it} = \alpha_i + \eta_i t + \varphi_i GDP_{it} + \theta_i REP_{it} + \varepsilon_{it}$ (with time trend) (8)

Where:

α = Fixed country effects

δ and η = Unit specific trend effects

When; cointegration has been discovered, we proceed to estimate the long-run relationships using FMOLS for cointegrated panel of variables.

Estimation of Cointegrated Relationships

The first step of this technique is to estimate a FMOLS relationship for each country in the panel then an un-weighted average of the coefficients of long-run price and income elasticities will be taken to get the respective panel estimates. The significance of the estimates will be determined by performing a t-test and checking the respective p-values using the formula below:

$$\frac{1}{\sqrt{n}}\sum Tn \qquad (9)$$

Where; *n* is the number of observation and T represents the respective t-statistics of the coefficients. This study employed the between-group FMOLS to estimate the long run relationship of the four models specified in equations 5 to 8 respectively.

Data Source

This study utilized an annual data set that covered the period 1978 to 2010 for 24 OECD countries namely: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, South Korea, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom, and the United States. The choice of this period and these countries were based on data availability. Of the 34 OECD countries, the relevant data sets for this survey were unavailable for the remaining 10 countries.

The data was sourced secondarily from the International Energy Agency (IEA). These data include gross domestic product per capita in billion 2000 US$ using Purchasing Power Parity (PPP); total energy consumption in kilo tonnes of oil equivalents per capita and electric power consumption in kilowatts/hour per capita. The indices of real electricity price and total energy price, was sourced from industry and households of the respective OECD countries using base year 2005 = 100.

ANALYSIS

Panel Unit Roots Test Results

Table 2 present results of the unit roots tests which follow an individual unit root process. The IPS (2003), ADF fisher chi square and PP fisher chi square tests all suggest that the variables are integrated of order 1, I (1). All the series were found to be significant at 1% after taking the first difference.

After investigating the stationarity properties of the variables, we can therefore conclude that the variables are stationary at first difference and integrated of the same order. We therefore proceed to test if there is a long run relationship among the variables.

Table 2: Results of Tests with Individual Unit Root Processes

Test method		**GDP**	**EPC**	**REP**	**TEC**	**TEP**
IPS	Level	3.49	6.22	2.01	1.00	6.32
		(1.00)	(1.00)	(0.97)	(0.84)	(1.00)
	First difference	-6.16***	-9.65***	-8.79***	-10.32***	-9.32***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
ADF Fisher Chi Square	Level	20.96	12.16	40.21	44.92	13.62
		(1.00)	(1.00)	(0.78)	(0.60)	(1.00)
	First difference	125.74***	203.47***	194.16***	206.82***	166.06***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
PP Fisher Chi Square	Level	29.62	17.43	48.43	43.99	23.54
		(0.98)	(1.00)	(0.46)	(0.64)	(1.00)
	First difference	137.00***	289.85***	310.82***	542.87***	343.54***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)

Notes: ***, ** and * denote significance at 1, 5 and 10% levels. P values are given in parenthesis and all tests assume presence of a unit root under the null hypothesis. The Fisher tests are computed using an asymptotic Chi-square distribution. The Modified Schwarz Information Criterion (MSIC) is used to select the optimal lag length.

Panel Cointegration Results

The results of the panel cointegration tests are presented in tables 3 to 9. The models of total energy and electricity demand have been estimated with and without a deterministic time trend to determine the impact of time trend on the relationships. Tables 3 and 4 present the results of the heterogeneous panel cointegration test by Pedroni (2004). When large negative values are found, the null of no cointegration is rejected except for the panel-v test whose null hypothesis states that there is cointegration among the series. Therefore, when large positive values are found, the panel-v test rejects the null of cointegration. The total energy demand model, when tested without a deterministic time trend shows that the variables are cointegrated except for the panel v-stat, panel r-stat and group r-stat. for the panel v-stat, the null of cointegration is rejected while the panel r-stat and group r-stat both fail to reject the null of no cointegration. However, according to Pedroni (1999), the Panel-ADF and group ADF tests, which have both found cointegration in the variables, have better small-sample properties than the other tabulated tests, and hence are more reliable (Lee and Lee 2010, Narayan et.al. 2007, Lee and Chang, 2008). When a deterministic time trend is added, results show that the panel PP, panel ADF and group PP tests are significant at 5% with no cointegration found by the other tests. Based on these results, the Pedroni (2004) cointegration tests suggest that TEC, TEP and GDP have a long run relationship among them.

Table 3: Pedroni Residual Cointegration Test Results (Total Energy Demand Model)

Test Statistic	Without trend	P-Value	With trend	P-Value
Panel v-stat	0.82	0.21	-0.54	0.70
Panel r-stat	-0.57	0.28	1.00	0.84
Panel PP stat	-3.02***	0.00	-2.23**	0.01
Panel ADF stat	-2.32***	0.01	-2.02**	0.02
[redacted]				
Group r-stat	0.25	0.60	1.99	0.98
Group pp. Stat	-4.33***	0.00	-3.75***	0.00
Group ADF Stat	-2.01**	0.02	-0.78	0.22

Note: The finite sample distribution for the seven statistics has been tabulated by Pedroni (2004) via Monte Carlo simulations.

The results of the heterogeneous panel cointegration test by Pedroni (2004) illustrated in Table 4 show that all the tests fail to reject the null of no cointegration among electricity consumption, electricity price and GDP except the panel v-stat which signifies cointegration at only 10% when a deterministic time trend is added.

Table 4: Pedroni Residual Cointegration Test Results (Electricity Demand Model)

Test Statistic	**Without trend**	**P-Value**	**With trend**	**P-Value**
Panel v-stat	-0.70	0.76	1.52*	0.06
Panel r-stat	1.48	0.93	2.78	1.00
Panel pp stat	-0.35	0.36	1.65	0.95
Panel ADF stat	0.14	0.55	1.96	0.97
[redacted]				
Group r-stat	2.82	1.00	4.28	1.00
Group pp. Stat	0.54	0.70	2.54	0.99
Group ADF Stat	1.04	0.85	3.38	1.00

Note: ***, ** and * denote significance at 1, 5 and 10% levels

Table 5: Kao's Residual Cointegration Test Results

	t-statistic	**P-Value**
ADF Statistic (Total Energy Demand Model)	-3.66***	0.00
ADF Statistic (Electricity Demand Model)	-3.41***	0.00

Notes: The ADF is the residual-based ADF statistic (Kao, 1999). ***, ** and * denote significance at 1, 5 and 10% levels. The Kao (1999) test does not allow for the addition of a deterministic time trend and heterogeneity in the panel observations.

The Kao (1999) test in Table 5 above suggests that cointegration exists in both models at 1% level of significance.

Table 6: Johansen Fisher Cointegration Test Results (Total Energy Demand Model (No trend added))

	Fisher Type (From trace stat)	**P- value**	**Fisher Stat (from max Eigen value)**	**P-value**
None	221.0***	0.00	199.5***	0.00
At most 1	76.12***	0.01	66.53**	0.04
At most 2	62.64*	0.08	62.64*	0.08

Notes: asymptotic p-values are computed using a chi-square distribution. ***, ** and * denote significance at 1, 5 and 10% levels. Fisher's test applies regardless of the dependent variable. These notes apply to the rest of the tables reporting the fisher's test results.

Table 7: Johansen Fisher Cointegration Test Results (Total Energy Demand Model (Trend added))

	Fisher Type (From trace stat)	P- value	Fisher Stat (from max Eigen value)	P-value
None	240.4***	0.00	201.4***	0.00
At most 1	88.69***	0.00	66.68**	0.04
At most 2	57.66	0.16	57.66	0.16

The results of the Johansen Fisher cointegration tests are presented in tables 6 to 9 respectively. The test was carried out with and without a time trend to observe its effect on the results. For both models, results show that there is at least one cointegrating vector in both models which is consistent with the Kao and Pedroni tests. When no deterministic time trend is added to both models, the possibility of more than one cointegrating vector is discovered in the total energy model at 10% level of significance which is not up of the standard 5% level of significance, hence can be ignored. However, in the electricity model, more than one cointegrating vector is discovered at 1% level of significance but due to the nature and objectives of this research work, having one cointegrating vector is enough to proceed to estimate the long-run relationships and test for causality and short-run estimates of income and price elasticities respectively. Therefore, after using the three different techniques to test for cointegration among the variables in the models of total energy and electricity demand, it can be concluded that the variables are cointegrated and there exists a long-run relationship among them. The next step is to estimate the relationships.

Table 8: Electricity Demand Model (No trend added)

	Fisher Type (From trace stat)	P- value	Fisher Stat (from max eigen value)	P-value
None	250.1***	0.00	189.3***	0.00
At most 1	112.6***	0.00	94.37***	0.00
At most 2	83.78***	0.00	83.78***	0.39

Table 9: Electricity Demand Model (Trend added)

	Fisher Type (From trace stat)	P- value	Fisher Stat (from max eigen value)	P-value
None	237.1***	0.00	186.6***	0.00
At most 1	97.51***	0.00	84.35***	0.00
At most 2	50.08	0.39	50.08	0.39

FMOLS Regression of Cointegrated Relationships

The results of the FMOLS estimation give country-by-country estimates of long-run price and income elasticities (Detailed estimates of the FMOLS are given in Tables 10 to 13. Summary of results are presented in Tables 14 and 15 respectively). The models have been estimated with and without a deterministic time trend to examine its impact on the estimates. In equation 10 (total energy without trend), GDP has a significant and positive impact on energy consumption in all countries except Denmark, Netherland and Sweden who all have insignificant estimates. For price elasticity, the estimates for Austria, Canada, Germany, Italy, Luxembourg, Netherlands, Portugal and USA are all statistically insignificant. The remaining 16 countries however produced significant and negative estimates of price elasticity which conforms to a priori expectation. However, when the panel estimates are computed, the long-run price and income elasticities are both statistically significant with the correct signs at -0.20 and 0.43 respectively. These results suggest that a 1% increase in energy price will reduce total energy consumption in the OECD by 0.2% in the long-run and a 1% increase in income will increase total energy consumption by 0.4% in the long-run.

In equation (11) where a deterministic time trend is added to the total energy demand model, conflicting results are discovered as more countries were found to produce insignificant estimates of long-run income elasticity including Austria, Belgium, Denmark, France, Italy, Japan, New Zealand and UK. However, five countries were found to produce insignificant estimates of price elasticity (Austria, Germany, Netherlands, Portugal and USA) as opposed to the seven insignificant estimates discovered in the relationship without a deterministic time trend. The panel estimates however give -1.0 for price elasticity and 0.63 for income elasticity respectively with the elasticity of income not significant. This might be due to the effect of the inclusion of the deterministic time trend which captures other exogenous effects that influence energy demand. The trend is negative and significant (-0.01), suggesting that OECD economies are energy saving rather than energy using and that other exogenous factors are significant in influencing energy demand. Due to the significance of both long- run income and price elasticities of the total energy demand model estimated without a trend (equation 10), it will be considered as the preferred model (An existing debate in literature is the inappropriateness of attempting to capture technical progress with a deterministic trend. More importantly, as results are aggregated in a panel context, a more appropriate method is still required to appropriately capture exogenous technical progress. A stochastic UEDT which is found to be important in estimating energy demand relationships cannot be estimated in a panel context; as far as it is understood in literature). The residual series from its regression will be used as an error correction term in the dynamic ECM to be specified.

In the electricity demand models (with and without trend), both models are statistically significant and of the correct signs which conforms to a priori expectation. This is so as the UEDT is also significant at 5% level but positive at 0.01. A positive UEDT could suggest that OECD economies are energy using (electricity in this case) meaning that more rigorous policies are desired to reduce electricity consumption. In equation (11), Canada, Germany, Italy and Luxembourg all produce estimates of price elasticity that are significant but of the wrong sign (positive). Positive estimates of price elasticity are also produced by Canada, Portugal and Switzerland when equation (12) is estimated.

However, as noted earlier, the panel estimates for both models are statistically significant with the correct signs. The results of equation (12) (without trend) appears to be more similar to the estimates of Lee and Lee (2010) and more importantly, only Canada, Finland, Ireland, New Zealand and Norway produced significant estimates of the time trend and thus can be ignored for this study. The electricity demand model without a deterministic trend is thus chosen as the preferred model. It shows that if electricity price in the OECD increases by 1%, OECD electricity consumption will reduce by 0.07%. On the other hand, a 1% increase in GDP will increase OECD electricity consumption by 0.92%. These results, as noted above are consistent with the findings of Lee and Lee (2010) who found that long-run income and price elasticities of total energy demand in the OECD are inelastic. The results of the elasticities of the electricity demand model are also similar to their findings as they found electricity demand to be income elastic and price inelastic. The residuals from the FMOLS of the preferred electricity demand model will be used in and ECM for electricity demand.

Table 10: FMOLS Results for Total Energy Demand Model (No trend added)

Countries	**Price**	**T stat**	**Income**	**T stat**
Australia	-0.23***	-4.09	0.41***	14.07
Austria	0.04	0.53	0.64***	11.89
Belgium	-0.26**	-2.63	0.60***	7.23
Canada	-0.11	-1.36	0.17**	2.42
Denmark	-0.16*	-1.1.94	0.06	1.02
Finland	-0.11**	-2.51	0.43***	14.27
France	-0.19***	-3.33	0.16***	3.42
Germany	0.05	0.69	-0.21***	-3.73
Greece	-0.65***	-8.63	0.94***	15.23
Hungary	-0.39***	-4.50	0.37***	2.93
Ireland	-0.11***	-2.84	0.39***	29.58

Italy	-0.09	-1.37	0.73***	14.70
Japan	-0.43***	-7.21	0.40***	7.49
Korea	-0.18**	-2.51	0.97***	29.02
Luxembourg	-0.10	-0.78	0.21***	4.01
Netherlands	0.05	0.55	0.03	0.38
New Zealand	-0.56***	-11.45	0.83***	14.26
Norway	-0.19***	-2.68	0.31***	7.26
Portugal	-0.11	-1.44	1.37***	27.99
Spain	-0.29***	-3.80	1.03***	26.97
Sweden	-0.26***	-2.31	0.22	1.57
Switzerland	-0.12***	-4.15	0.21***	4.50
UK	-0.28***	-7.19	0.07***	3.40
USA	-0.01	-0.12	-0.13***	-2.73
Panel	-0.20	-14.93	0.43	48.48

Table 10...

Notes: *, ** and *** denote significance at 10%, 5% and 1% significance levels.

Table 11: FMOLS Results for Total Energy Demand Model (Deterministic time trend added)

Countries	Price	T stat	Income	T stat	Trend	Tstat
Australia	-0.23***	-4.98	0.22***	1.46	0.00	1.18
Austria	0.03	0.43	0.26	0.40	0.00	0.56
Belgium	-0.23**	-2.06	0.78	0.76	-0.00	-0.17
Canada	-0.14*	-1.95	0.59**	2.73	-0.00	-0.18
Denmark	-0.15*	-1.73	0.15	0.35	-0.00	-0.18
Finland	-0.08**	-2.04	0.20**	2.37	0.00***	0.01
France	-0.17**	-2.52	0.40	0.89	-0.00	-0.52
Germany	-0.07	-0.99	-0.93**	-2.54	0.01**	2.01
Greece	-0.27***	-6.18	0.23***	3.23	0.02***	10.36
Hungary	0.11**	2.56	0.65***	12.36	-0.02	-12.13
Ireland	-0.10***	-2.85	0.52***	7.83	-0.00*	-1.93
Italy	-0.29***	-3.82	0.16	0.86	0.01***	3.13
Japan	-0.46***	-7.20	0.20	1.43	0.00	1.43
Korea	0.42**	2.50	2.89***	5.60	-0.11***	-3.69
Luxembourg	0.48**	2.40	1.94***	3.68	-0.07***	-3.28
Netherlands	0.13	1.37	1.41***	2.97	-0.03***	-2.93
New Zealand	-0.41***	-7.33	0.19	1.01	0.00***	3.38
Norway	-0.12**	-2.07	0.75***	5.42	-0.01***	-3.31

Table 11...

Portugal	-0.06	-0.64	1.55***	7.76	-0.00	-1.02
Spain	-0.20*	-1.85	1.43***	3.40	-0.00	-0.93
Sweden	-0.26***	-3.86	-0.27*	-1.67	0.01***	3.17
Switzerland	-0.12***	-4.11	0.33*	1.91	-0.00	-0.70
UK	-0.28***	-7.54	0.27	1.61	-0.00	-1.25
USA	0.06	1.53	1.26***	4.30	-4.71	0.00
Panel	-0.10	-10.80	0.63	1.25	-0.01	-2.39

Note: *, ** and *** denote significance at 10%, 5% and 1% significance levels.

Table 12: FMOLS Results for Electricity Demand Model (No trend added)

Countries	**Price**	**T- stat**	**Income**	**T- stat**
Australia	0.05	0.16	1.15***	9.86
Austria	0.06	0.76	1.08***	24.56
Belgium	-0.29**	-2.25	1.07***	12.40
Canada	0.71***	4.07	0.20*	0.10
Denmark	-0.47***	-3.02	0.96***	8.96
Finland	-0.71***	-4.16	1.02***	11.48
France	0.46***	3.33	1.75***	11.48
Germany	0.16*	1.71	0.39***	5.48
Greece	-0.32*	-1.69	1.48***	6.47
Hungary	0.14***	3.72	0.36***	4.93
Ireland	-0.15***	-3.04	0.70***	37.97
Italy	0.08*	1.72	1.39***	27.42
Japan	-0.22*	-1.90	0.98***	10.68
Korea	0.33	1.21	1.73***	13.66
Luxembourg	0.22*	1.89	0.36***	11.43
New Zealand	-0.54***	-4.15	-0.24	-1.22
Netherlands	-0.07***	-3.51	0.99***	61.10
Norway	0.10	0.80	0.32***	3.92
Portugal	0.00	0.11	1.74***	19.51
Spain	-0.08	-1.42	1.39***	28.03
Sweden	-0.81***	-5.28	1.09***	6.70
Switzerland	0.18*	1.92	1.30	12.43
UK	-0.13**	-2.26	0.47***	10.58
USA	-0.26**	-2.50	0.50***	6.27
Panel	-0.07	-2.81	0.92	70.26

Note: *, ** and *** denote significance at 10%, 5% and 1% significance levels.

Table 13: FMOLS Results for Electricity Demand Model (Deterministic time trend added)

Countries	**Price**	**T- stat**	**Income**	**T- stat**	**Trend**	**T-stat**
Australia	-0.15	-0.91	-0.97**	-2.63	0.04	5.79
Austria	0.04	0.49	0.61	1.01	0.00	0.43
Belgium	-0.46***	-3.01	0.08	0.14	0.02	0.12
Canada	1.32***	5.08	1.36***	3.15	-0.03**	-2.72
Denmark	-0.47***	-2.46	0.93	1.28	0.00	0.04
Finland	-0.54***	-8.91	0.02	0.19	0.02***	9.71
France	0.45**	2.50	1.72**	2.69	0.00	0.04
Germany	0.16*	1.71	0.39***	5.48	0.01	1.27
Greece	-0.01	-0.19	-0.03	-0.41	0.04	20.70
Hungary	0.11	2.70	0.36***	4.64	0.00	0.83
Ireland	-0.23***	-12.15	0.29***	7.56	0.02***	10.02
Italy	-0.14***	-3.20	0.68***	5.34	0.02	5.90
Japan	-0.17	-1.63	0.87***	6.33	0.00	0.74
Korea	0.03	0.18	1.05***	5.79	0.03	3.62
Luxembourg	0.18	1.50	0.41**	2.71	-0.00	-0.23
New Zealand	-0.54***	-4.15	-0.24	-1.22	0.03***	8.54
Netherlands	-0.07***	-3.93	0.83***	7.57	0.00	1.42
Norway	0.19	1.53	1.33**	2.45	-0.03*	-1.89
Portugal	0.04*	1.66	0.72	9.83	0.03	13.73
Spain	-0.16***	-4.44	0.26	1.14	0.03	4.94
Sweden	-0.80***	-5.85	1.02**	2.26	0.00	0.25
Switzerland	0.17*	1.73	1.36***	3.98	-0.00	-0.24
UK	-0.13**	-2.24	0.45	1.55	0.00	0.09
USA	-0.28	-3.03	-0.03	-0.10	0.01	1.80
Panel	-0.06	-9.10	0.56	14.44	0.01	17.33

Note: *, ** and *** denote significance at 10%, 5% and 1% significance levels.

Summary of FMOLS Results

Table 14: Total Energy Demand

Estimated Elasticity	Price	Income
Panel Coefficients	-0.20***	0.43***
T- stat	-14.93	48.48

Table 15: Electricity Demand

Estimated Elasticity	Price	Income
Panel Coefficients	-0.07***	0.92***
T –stat	-2.81	70.26

In summary, the inelastic nature of the long-run price and income elasticities of the preferred total energy demand model for the OECD suggests that energy demand is slow in responding to changes in energy price and income in the long-run. For price elasticity, it also suggests that the use of pricing policies as instruments to encourage more efficient use of energy in the OECD might not be very effective in promoting energy efficiency and reducing carbon emission. In the electricity demand model, large size of the income elasticity suggests that electricity consumption in the OECD responds faster to changes in income. Inelastic electricity price also suggests that electricity price is not a significant determinant of electricity demand in the OECD and pricing policies might not be effective in reducing electricity consumption in the long-run.

Estimates of Short-Run Error Correction Model

Based on the estimation of the long run relationships of total energy and electricity using the FMOLS technique, the residuals from our long-run regression are used as an error correction term (ECT) in an ECM to determine short-run price and income elasticities for both models.

Table 16: Short-Run Price and Income Elasticities

Variables	**Elasticity**	**P -Value**
ΔTECt-2	0.15***	0.00
ΔTEP	-0.09***	0.00
ΔGDP	0.40***	0.00
ECTt-1	-0.32***	0.00

Table 16 reports a summary of the results of the short run error correction model for total energy demand in OECD. Lags of up to two years were used for the variables and after dropping the insignificant variables from the model, the preferred model with the significant coefficients are presented. It shows that the past two periods (years) of total energy consumption, total energy price and GDP are all significant in explaining changes in total energy consumption in the short term. The elasticities of price and income are both inelastic and conform to a priori expectation. According to energy economics literature, short run elasticities are lower than long run elasticities as households and industries are not flexible enough to adjust to changes in income and prices. The ECT is -0.32 it indicates that nearly one-third of the adjustment in total energy demand in the OECD occurs within a year.

Table 17: Electricity Demand Model

Variables	Elasticity	P -Value
ΔEPC_{t-1}	0.06**	0.10
ΔREP	-0.02*	0.06
ΔGDP	0.39	0.00
ΔGDP_{t-2}	0.40	0.00
ECT_{t-1}	-0.14	0.00

Table 18: Summary of Elasticities

	Total Energy Demand Model	
	Price	Income
Long run	-0.20***	0.43***
Short run	-0.09***	0.40***
	Electricity Demand Model	
	Price	Income
Long run	-0.06***	0.56***
Short run	-0.03**	0.34***

In Table 17, the estimates of the short run elasticities of electricity demand model for the OECD are presented with the coefficient of the previous year's electricity consumption found to be significant. More so, the coefficient of the two-year lag of GDP is also significant in the preferred model. Short run price elasticity of electricity demand is -0.03 and lower in absolute terms than the -0.06 long-run price elasticity suggesting it is more inelastic in the short run. This conforms to a priori expectation. Short run income elasticity of electricity demand is also inelastic at 0.34 and lower than the long-run coefficient at 0.92. The one-period lagged ECT, -0.23 suggests that 23% of adjustments in electricity demand in the OECD takes place within a year. The summary of all the elasticities is presented in table 18.

CONCLUSION

This study estimated the demand for total energy and electricity in 24 OECD countries from 1978 to 2010 using different panel data estimation techniques. It also follows the two-stage Engle and Granger procedure in investigating the relationship between energy consumption and

GDP and the relationship between electricity consumption and GDP. This research contributes to the existing literature as it builds upon the work of Lee and Lee (2010) while also employing other estimation techniques for consistency and robustness. All the variables were found to be stationary at first difference. The Pedroni and Kao tests suggested cointegration and more than one cointegrating vector was discovered by the Johansen Fisher test. The discovery of more than one cointegrating vector in the Johansen Fisher test was however not dealt with in this study due to the possibility of proceeding to estimate when at least one cointegrating vector has been discovered. It was therefore concluded that the variables have a long run relationship among them.

FMOLS was used to estimate the cointegrated relationships to derive the long-run price and income elasticities for the total energy and electricity demand models. The results showed that long-run price and income elasticities for total energy are inelastic. Electricity price was also found to be inelastic but income elasticity in the electricity model is elastic. In the short-run, the estimates of the price and income elasticities are also inelastic but relatively more inelastic than the long run estimates which conforms to our a priori expectation. This is reasonable as most appliance stocks are fixed thereby not allowing for short-term adjustment to energy and cost saving alternatives. In the long-run, increase in price will lead to more efficient use of appliance stock e.g machinery, cars and heating appliances and other energy saving measures due to their underlying importance. The inelastic nature of long-run price and income elasticities of total energy demand shows that energy consumption in the OECD responds slowly to changes in energy price and income. This means that the implementation of pricing policies to reduce CO_2 emissions and promote efficiency might not achieve satisfactory results.

Based on the findings, a recommendation is for policy makers to concentrate on encouraging energy efficiency as a way to reduce energy and electricity consumption. This can be done through many ways; manufacturers and other stake holders can be encouraged to invest in more new fuels efficient technologies (e.g. electric cars, gas powered appliances) and the switching of fuels to cleaner and more efficient alternatives (e.g switching from coal to gas in electricity generation) without it bearing much burden on cost. Consumers can also be sensitized on the importance of energy saving approaches to use of appliance stock to help reduce carbon emission and its negative impact on the environment.

SCOPE FOR FURTHER STUDIES

Further studies in this area can look at some other important variables like temperature and exchange rate and assess their impact on the elasticities. More so, the impact of price can be further assessed in the causality relationship by exploring the relationship that exists among price, income and energy consumption. With respect to the methodology, further scholars can extend this research study by incorporating a stochastic trend in panel context to capture not only technical progress but other exogenous non-economic factors like tastes, preferences and lifestyle.

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