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Article

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Comparative sectoral price elasticities of U.S. energy demand

Kwame Asiam Addey*[1], Saleem Shaik[1] and Kekoura Sakouvogui[2]

Abstract: A sustainable energy system is key for addressing the world's environmental and social challenges. The U.S is the second largest consumer of energy, with increased energy consumption in the previous half-century. To curb energy demand, it is essential to understand the relative price elasticities among the four main U.S energy consumption sectors; residential, industrial, commercial and transportation. The aim of this study is to present a theory-based comparative analysis of U.S sectoral energy price elasticities using the pooled mean group model. The speed of adjustment for the four sectors were −0.43, −0.41, −0.55 and −0.37, suggesting the existence of long-run relationships. The short-run own-price elasticities were −0.17, −0.39 and −0.27 for the commercial, industrial and residential sectors while the long-run own-price elasticities were −0.33, −0.45 and −0.20 for the commercial, residential and transportation sectors. We conclude that the residential sector readjusts to long-run equilibrium at a faster rate than the three other sectors. In the long run, this sector will yield a higher response to a price change. We suggest that price policies aimed at reducing energy demand should primarily target the residential sector, followed by the commercial and transportation sectors.

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*Corresponding author: Kwame Asiam Addey, Center for Agric. Policy and Trade Studies, North Dakota State University, USA
E-mail: kwame.addey@ndus.edu

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Lanouar Charfeddine, Finance and Economics, Qatar University, Doha, Qatar

Additional information is available at the end of the article

ABOUT THE AUTHORS

Kwame Asiam Addey holds an MPhil. Agricultural Economics degree from University of Ghana, Legon. He also holds a Master of Science in Applied Economics from North Dakota State University, where he is currently completing his PhD in Statistics. He is a research assistant at the Center for Agric. Policy and Trade Studies. His research and teaching interests include actuarial science, operations research, econometrics and microeconomics.

Dr. Saleem Shaik, Professor & Director, Center for Agricultural Policy and Trade Studies at North Dakota State University. His research on risk analysis, economics of US/India/World crop yield distributions, and efficiency/productivity focusses on US farm bill/policies and US-World trade agreements.

Kekoura Sakouvogui holds a PhD degree in Statistics from North Dakota State University. He is currently a Mathematical Statistician at the Census Bureau, U.S Department of Commerce, Washington D.C. His research interests are econometric and statistical modeling, predictive modeling, survey design, quantitative finance and policy analysis.

PUBLIC INTEREST STATEMENT

The importance and consumption of energy has increased drastically in our daily lives over the years. However, the increased consumption of energy is associated with increased greenhouse gas (GHG) emissions that may be harmful to the existence of humanity. Considering this, world leaders have sought for alternative ways to curb these emissions. The need to improve the energy consumption efficiency has become paramount among the alternatives. The U.S is the second major consumer of energy and provides several incentives to motivate the efficient consumption of energy among its populace. The objective of this study is to examine the relative price elasticities among the four main energy demand sectors in the U.S. Understanding the relative price elasticities is important for policy makers to formulate price policies in the relevant sectors to contract energy demand. This study revealed that price policies will reduce energy demand in the residential sector at a faster rate, followed by the commercial and transportation sectors.

Keywords: elasticity; PMG; energy demand; speed of adjustment; 48 U.S. states; 1970 to 2015
JEL Classification Numbers: E64; N7; Q41

1. Introduction

A sustainable energy system is key for addressing the world's environmental and social challenges (Sandin, Lena Neij, & Mickwitz, 2019). The need to reduce greenhouse gas (GHG) emissions led to the Paris agreement within the United Nations Framework Convention on Climate Change (UNFCCC) in 2016. In order to meet the long-term goal[1] of this agreement, some ambitious mitigation efforts such as energy consumption regulation may be required (Rajbhandari, Limmeechokchai, & Masui, 2019). To regulate energy consumption, policy makers are likely to formulate policies that affect prices. As such, the knowledge of consumer price elasticities of demand is important.

The United States (U.S.) is the second largest consumer of energy in the world, only surpassed by China. The four main energy consumption sectors of the country are commercial (CS), industrial (IS), residential (RS) and transportation (TS). Since 1970, energy consumption has increased for all but the industrial sector (see Figure 1). The trends of the four sectors are hierarchically consistent over the years, with the industrial sector being the highest consumption sector followed by the transportation, residential, and commercial sectors. The varying energy demand needs among these four sectors justifies the variation of prices. Figure 2 shows that the prices for all sectors have increased since 1970. Generally, an increased trend in energy use is a sign of increased output (Burke & Csereklyei, 2016) or evolution from agriculture (subsistence or mechanized) through industrialization to services (Todaro & Smith, 2012). Despite sectors being connected by certain inputs or resources (Addey, 2019), the effect of this is an irregular dispersal of energy demand across these sectors. Meanwhile, energy demand and supply gaps have the tendency of creating adverse effect for an economy (Rehman, Deyuan, Chandio, & Hussain, 2018). Other energy economists are of the view that increased energy demand across sectors may not only be due to economic growth but also due to the inefficient use among consumers (Filippini & Hunt, 2012). The objective of this study is to present a theory-based comparative analysis of the sectoral energy price elasticities of demand in U.S. using the pooled mean group (PMG) model.

The knowledge of the relative response to energy prices in these sectors will enable policy makers to choose price policies relevant to these sectors. Charfeddine, Klein, and Walther (2018) noted that prices are important in determining energy demand and further indicated that energy is essential for economic growth in the U.S. Despite the U.S. having success in energy productivity through technological advances and utility sector innovations, energy consumption has struggled with efficiency over the years (Hayes, Baum, & Herndon, 2013). This phenomenon has been among the contributing

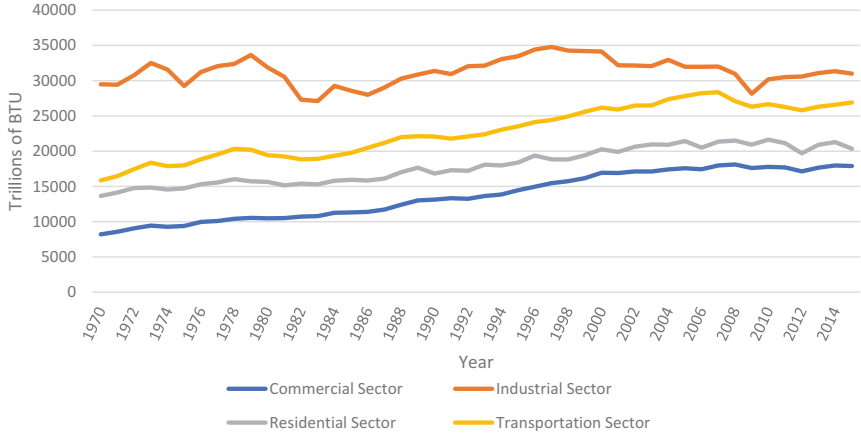

Figure 1. Sectoral energy consumption in Trillions of British thermal units.

Source: Energy Information Administration (EIA 2017)

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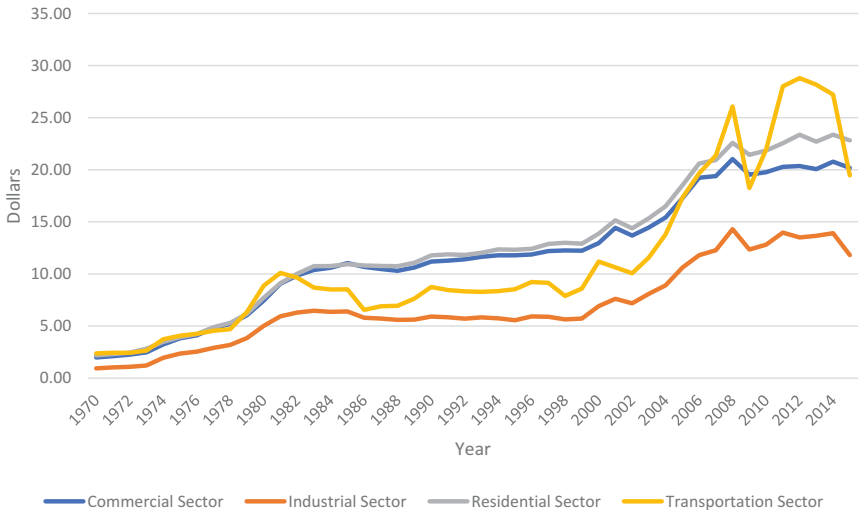

Figure 2. Sectoral energy prices in Dollars per unit.

Source: EIA (2017)

factors for the formulation of energy policies in the country. Examples of such policies include provision of energy efficiency tax credits, public benefits funds, grants, loans or property-assessed clean energy financing. Majority of the energy price policies in the U.S. are sector-oriented but practically few of the numerous studies on energy demand and price elasticity have addressed the comparative energy price elasticities among the four major consumption sectors. Gautam and Paudel (2018) is one of the few studies that estimates the sectoral demand for electricity using the pooled mean group. Their study examined three of the sectors for the Northeastern U.S. The residential, commercial and industrial sectors yielded long-run income elasticities of 0.93, 0.53 and 1.95, respectively. The long-run cross price elasticities for natural gas in the residential and commercial sectors were 0.095 and 0.105, respectively. Their study focused on a few states in the U.S. and only three sectors. Due to this, their findings cannot be generalized to other states considering the extreme geographic and climate variations of states in the U.S. Hence, our study focusses on all the four sectors for the 48 contiguous U.S. states from 1970 to 2015.

The importance of energy demand response to prices is so explicit that section 529(a) of the Energy Independence and Security Act of 2007 (EISA, 2007) mandates the Federal Energy Regulatory Commission (FERC) to conduct a national assessment of energy demand response potential. The key obligations to be reported to congress under this mandate were: 1) estimation of nationwide demand response potential in 5 and 10-year horizons at the state level; 2) estimation of how much of the potential can be achieved within the specified time horizons; 3) identification of barriers to demand response programs offering flexible, non-discriminatory and fairly compensatory terms for the services and benefits made available; and 4) provision of recommendations for overcoming any barriers.[2] Our study focusses on the first obligation.

Furthermore, price policies have been suggested to contract energy demand. Such policies have the potential to help energy providers save production resources through reductions in peak demand. A FERC[3] (2009) report listed 25 barriers that make energy demand response programs and recommendations ineffective. Among these factors are ineffective demand response program design and high cost of some enabling technologies. Hence, to implement price policies for consumption reduction, it is essential to understand the behavioral response by sector since technologies vary by sector.

The variables employed to examine the determinants of energy demand in this study were drawn from relevant and independent literature. Narayan and Smyth (2007) used the panel cointegration analysis to estimate long-run income and oil price elasticities for 12 countries in the Middle East spanning from 1971 to 2002. Their results revealed that the demand for oil was

slightly income elastic and highly price inelastic in the long-run. The short-run own-price elasticity was −0.0008 while the long-run ranged from −0.002 to −0.071. The short-run income elasticity was 0.1715 while long-run income elasticity ranged from 0.444 to 1.520. Alberini and Filippini (2011) studied the response of residential electricity demand to price, with focus on the effect of measurement error. Their study used data from 1995 to 2007 for the 48 contiguous U.S states using two dynamic partial adjustment models; the Kiviet corrected least square dummy variables (LSDV) and the Blundell-Bond estimators. They found that the long-run elasticities produced by the Blundell-Bond system GMM were the largest followed by the bias-corrected LSDV and the conventional LSDV. They found that the use of a carbon tax or another price-based policy may be effective in discouraging residential electricity consumption and hence curb greenhouse gas emissions.

In estimating the price elasticities for residential electricity demand in Japan from 1990 to 2007, Okajima and Okajima (2013) used the generalized method of moments estimator due to its advantage of reducing biasedness of estimates. The variables considered in their study were income per capita, heating degree days, cooling degree days and electricity price. Their results found that an increase in price of 1% led to a 0.4% decrease in the residential consumption of electricity. Income, heating and cooling degree days were positively correlated with electricity consumption. Moller (2017) estimated energy demand, substitution and response to environmental taxation in eight subsectors of the Danish economy. The sectors considered in their study were the agricultural, food manufacturing, chemical manufacturing, machine, vehicle manufacturing, other manufacturing, construction, trade and other services. Using a cointegrated VAR, they concluded that environmental taxation can act as an external shock for energy demand substitution. Based on the studies reviewed, we used energy prices, consumer income and technology in this study.

The paper is organized into five sections. Following the introduction, section two deals with the methodology and briefly discusses the pooled mean group method of estimation. The third section describes the data and construction of the variables. The penultimate section of this paper presents the results and discussions while section five summarizes the findings and presents the conclusions.

2. Methodology

2.1. Panel unit root test

Unit root tests are conducted in time-series analysis to correct for potential non-stationarity of the variables. Panel unit root test has become common since its first use by Levin and Lin (1992). However, it is quite challenging due to the heterogeneity of cross-sections. Due to that, they employed a pooled estimator of the autoregressive parameter based on the assumption of cross-sectional independence. Four types of panel unit root tests were conducted in this study: 1) Levin-Lin-Chu (LLC), 2) Im, Pesaran and Shin (IPS), 3) ADF Fisher Chi-square and 4) PP Fisher Chi-square. Even though the results from all four are reported, the LLC results are used in the discussion due to the nature of the data. The LLC unit root test performs well when N and T lie between 10 and 250; and 25 and 250, respectively (Levin, Lin, & Chu, 2002).

2.2. Pooled mean group estimation

Following Pesaran, Shin, and Smith (1999)[4], if a given dataset has time periods, $t = 1, 2, ., T,$ and cross-sectional units, $i = 1, 2, ., N,$ the desire to estimate an $ARDL(1, 1, 1, 1)$ model presents equation (1);

$$Y_{it} = \lambda_{ij} Y_{i,t-1} + \sum_{j=0}^{1} \delta_{ij}^{'} X_{i,t-j} + \mu_i + \varepsilon_{it} \quad (1)$$

Equation (1) is grouped into three components; (1) Dependent variable (Y_{it}), (2) Lagged dependent variable ($Y_{i,t-1}$)and (3) Explanatory variables ($X_{i,t-j}$).

The fixed effects are represented byμ_i. The coefficients of j period lagged dependent variables, λ_{ij} are scalar values, and δ_{ij} are $k \times 1$ coefficient vectors. Equation (1) can be rearranged into an error correction model of the form:

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$$\Delta Y_{it} = \emptyset_{1i}\left(Y_{i,t-1} - \beta_{j,i}X_{i,t-1}\right) + \delta^{*'}_{1,i}\Delta X_{it} + \mu_i + \varepsilon_{it} \quad (2)$$

where $\emptyset_{1i}$= —(1-λ_i), $\beta_{j,i} = \frac{\sum_{j=0}^{1}\delta_{ij}}{1-\lambda_i}$ Following this form, we write the empirical model specification for the four energy consumption sectors as:

$$\Delta InCom_{it} = \emptyset_i\left(InCom_{it,-1} - \beta_{1i}lnw_{it}^{Com} - \beta_{2i}lnw_{it}^{Ind} - \beta_{3i}lnw_{it}^{Res} - \beta_{4i}lnw_{it}^{Tran} - \beta_{5i}Pool_{it} - \beta_{6i}lnPerCap_{it} - \beta_{7t}Tech_{it}\right) - \delta_{1i}\Delta Inw_{it}^{Com} - \delta_{2i}\Delta Inw_{it}^{Ind} - \delta_{3i}\Delta Inw_{it}^{Res} - \delta_{4i}\Delta Inw_{it}^{Tran} - \beta_{5i}\Delta Pool_{it} - \delta_{6i}\Delta InPerCap_{it} - \delta_{7i}\Delta Tech_{it} + u_i + \varepsilon_{it} \quad (3)$$

$$\Delta InInd_{it} = \emptyset_i\left(InInd_{it,-1} - \beta_{1i}lnw_{it}^{Ind} - \beta_{2i}lnw_{it}^{Com} - \beta_{3i}lnw_{it}^{Res} - \beta_{4i}lnw_{it}^{Tran} - \beta_{5i}Pool_{it} - \beta_{6i}lnPerCap_{it} - \beta_{7t}Tech_{it}\right) - \delta_{1i}\Delta Inw_{it}^{Com} - \delta_{2i}\Delta Inw_{it}^{Ind} - \delta_{3i}\Delta Inw_{it}^{Res} - \delta_{4i}\Delta Inw_{it}^{Tran} - \beta_{5i}\Delta Pool_{it} - \delta_{6i}\Delta InPerCap_{it} - \delta_{7i}\Delta Tech_{it} + u_i + \varepsilon_{it} \quad (4)$$

$$\Delta InRes_{it} = \emptyset_i\left(InRes_{it,-1} - \beta_{1i}lnw_{it}^{Res} - \beta_{2i}lnw_{it}^{Ind} - \beta_{3i}lnw_{it}^{Com} - \beta_{4i}lnw_{it}^{Tran} - \beta_{5i}Pool_{it} - \beta_{6i}lnPerCap_{it} - \beta_{7t}Tech_{it}\right) - \delta_{1i}\Delta Inw_{it,}^{Com} - \delta_{2i}\Delta Inw_{it,}^{Ind} - \delta_{3i}\Delta Inw_{it}^{Res} - \delta_{4i}\Delta Inw_{it}^{Tran} - \beta_{5i}\Delta Pool_{it} - \delta_{6i}\Delta InPerCap_{it} - \delta_{7i}\Delta Tech_{it} + u_i + \varepsilon_{it} \quad (5)$$

$$\Delta InTran_{it} = \emptyset_i\left(InTran_{it,-1} - \beta_{1i}lnw_{it}^{Tran} - \beta_{2i}lnw_{it}^{Ind} - \beta_{3i}lnw_{it}^{Res} - \beta_{4i}lnw_{it}^{Com} - \beta_{5i}Pool_{it} - \beta_{6i}lnPerCap_{it} - \beta_{7t}Tech_{it}\right) - \delta_{1i}\Delta Inw_{it}^{Com} - \delta_{2i}\Delta Inw_{it}^{Ind} - \delta_{3i}\Delta Inw_{it}^{Res} - \delta_{4i}\Delta Inw_{it}^{Tran} - \beta_{5i}\Delta Pool_{it} - \delta_{6i}\Delta InPerCap_{it} - \delta_{7i}\Delta Tech_{it} + u_i + \varepsilon_{it} \quad (6)$$

The error correction parameter, $\emptyset_i$ is a measure of the speed of adjustment. In order to conclude that there is convergence to long-run equilibrium in the case of any disturbance, this parameter must be negative and significant. A summary of the key notations for the equations can be found in Table 1.

Table 1. Summary of key notations

Symbol	Meaning
Com_{it}	share of energy consumed by the commercial sector in the state
$Com_{it,-1}$	lag of share of energy consumed by the commercial sector in the state
Ind_{it}	share of energy consumed by the industrial sector in the state
$Ind_{it,-1}$	lag of share of energy consumed by the industrial sector in the state
Res_{it}	share of energy consumed by the residential sector in the state
$Res_{it,-1}$	lag of share of energy consumed by the residential sector in the state
$Tran_{it}$	share of energy consumed by the transportation sector in the state
$Tran_{it,-1}$	lag of share of energy consumed by the transportation sector in the state
Pool	pooled period for technological change
Tech	annual technological change
$PerCap_{it}$	average per capita GDP of the state
w_{it}^{Com}	average price of energy within the commercial sector
$w_{it,-j}^{Com}$	lag of the average price of energy within the commercial sector
w_{it}^{Ind}	average price of energy within the industrial sector
$w_{it,-j}^{Ind}$	lag of the average price of energy within the industrial sector
w_{it}^{Res}	average price of energy within the residential sector
$w_{it,-j}^{Res}$	lag of the average price of energy within the residential sector
w_{it}^{Tran}	average price of energy within the transportation sector
$w_{it,-j}^{Tran}$	lag of the average price of energy within the transportation sector

3. Data and descriptive statistics

A balanced panel dataset comprising of a cross-section of the 48 contiguous U.S. states, spanning from 1970 to 2015 for the four energy consumption sectors was compiled. The U.S. Energy Information Administration (EIA) publishes energy production and sectoral consumption in various forms at the state and national levels. To evaluate the relative sectoral elasticities of energy demand, we obtained the annual total energy expenditure by the commercial, industrial, residential and transportation sectors at the state level in million dollars. We further obtained the annual consumption in British thermal units (Btu). The dependent variable is the share of sectoral energy consumption by the state. To obtain the shares, the total energy consumed by each state for all four sectors were summed. The share was then calculated by dividing each state's sector consumption by its total consumption of all four sectors. Dividing the energy expenditure by the annual consumption gave us the unit prices. The independent variables include unit prices of energy, per capita GDP and technology. The per capita GDP was obtained by dividing the states' GDP by their respective populations. The state GDP was obtained from the Bureau of Economic Analysis (BEA) database while the population data were obtained from the Federal Reserve Economic Database (FRED St. Louis). The share of energy consumed, prices and income were all logged.

Technology was incorporated based on the assumption that every year yields a one percent increase in technology (Jorgenson & Fraumeni, 1981; Popp, 2001). We added a second technology term wherein we grouped the years. The assumption for this is that it takes some time for technology to be adopted. Rosenberg (1976) noted that systemic technologies such as energy and information technology require the development of complementary skills and capital goods, hence takes time to be adopted. There is no consensus on the duration of diffusion of technology. Grübler (1996) suggested that changes in technology and social techniques are not one-time, discrete events but rather a process characterized by time lags and often lengthy periods of diffusion. Based on Saundry (2019)[5] characterization of the U.S. primary energy consumption pattern over the period, we grouped the second technology term into three. The first period starts from 1970 to 1985. The second was from 1986 to 2000 while the third period begins from 2001 to 2015.

The mean price of energy was US$11.80, US$6.91, US$12.60 and US$11.28 per unit for the commercial, industrial, residential and transportation sectors, respectively, over the period. The average shares of consumption were 0.15, 0.20, 0.23 and 0.42 for the commercial, industrial, residential and transportation sectors, respectively. The per capita GDP ranged from US$3192.76 to US$80,587.48. Table 2 presents the summary statistics of variables used in the analysis.

4. Empirical results and discussions

This section presents results from an empirical analysis of the sectoral energy demand in U.S. The panel unit root test was conducted using alternative methods, i.e., LLC, IPS, ADF and PP. These methods make different asymptotic assumptions regarding the panel structure and are individually important for varying relationships between the number of time periods and cross-sections. The LLC was selected based on its relevance to the data set used for this analysis. The PMG was then estimated for each of the sectors.

4.1. Unit root test results of variables

The variables tested were energy demand shares, unit prices and per capita GDP. Table 3 shows the LLC, IPS, ADF and PP test for unit roots conducted at levels while Table 4 presents the results for these four tests at first difference levels. The null hypothesis of stationarity is performed at the 1%, 5% and 10% significance levels. In Table 3, the results indicate that all the variables are stationary for the LLC. However, not all variables exhibited stationarity for the IPS, ADF and PP tests. For consistency, the variables were first-differenced and re-tested. From Table 4, the results show that all variables are stationary for all the four tests at first difference. The stationarity at first difference indicates that the model is stable.

Table 2. Descriptive statistics

Variable	Total	Mean	Std. Dev.	Median	Maximum	Minimum	Skewness	Kurtosis
Prices ($/Btu)								
Commercial Sector	2208	11.80	6.24	11.53	31.88	1.11	0.39	2.82
Industrial Sector	2208	6.91	4.34	5.98	25.88	0.52	1.07	4.40
Residential Sector	2208	12.60	6.96	11.65	35.18	1.42	0.52	2.81
Transportation Sector	2208	11.28	7.49	8.87	31.10	1.95	1.10	3.16
Shares								
Commercial Sector	2208	0.15	0.04	0.14	0.33	0.05	0.87	4.36
Industrial Sector	2208	0.20	0.08	0.19	0.64	0.05	1.29	6.11
Residential Sector	2208	0.23	0.05	0.23	0.37	0.06	0.02	2.90
Transportation Sector	2208	0.42	0.07	0.42	0.64	0.24	0.21	2.61
Other Variables								
Per Capita GDP (US$ p.a)	2208	26,278.4	16,120.88	23,873.64	80,587.48	3,192.76	0.55	2.51
Population	2208	5,369,134	5,760,129	3,712,587	39,000,000	332,416	2.56	11.42

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Table 3. Unit root tests for variables at levels

Variable	Levin, Lin & Chu t*		Im, Pesaran & Shin		ADF-Fisher Chi Sq.		PP-Fisher Chi Sq.		Decision Rule from LLC
	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.	H_0: Presence of unit root
Commercial Sector DD	−10.61	0.0000	−2.09	0.0185	129.28	0.0133	179.43	0.0000	No unit root
Industrial Sector DD	2.44	0.0073	−1.69	0.0453	125.41	0.0236	122.17	0.0370	No unit root
Residential Sector DD	−8.95	0.0000	−4.12	0.0000	153.50	0.0002	175.99	0.0000	No unit root
Transportation Sector DD	−8.58	0.0000	−3.19	0.0007	130.30	0.0114	137.54	0.0035	No unit root
Transportation Sector Price	−9.07	0.0000	−2.91	0.0018	106.77	0.2126	85.54	0.7691	No unit root
Commercial Sector Price	−21.07	0.0000	−13.59	0.0000	371.118	0.0000	413.09	0.0000	No unit root
Industrial Sector Price	−17.73	0.0000	−11.26	0.0000	300.56	0.0000	312.56	0.0000	No unit root
Residential Sector Price	−21.42	0.0000	−13.08	0.0000	355.405	0.0000	387.67	0.0000	No unit root
Per Capita GDP	−30.55	0.0000	−19.69	0.0000	582.10	0.0000	1105.28	0.0000	No unit root

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Table 4. Unit root tests for variables at first difference

Variable	Levin, Lin & Chu t*		Im, Pesaran & Shin		ADF-Fisher Chi Sq.		PP-Fisher Chi Sq.		Decision Rule from LLC
	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.	H_0: Presence of unit root
Commercial Sector DD	−41.08	0.0000	−39.26	0.0000	1271.29	0.0000	1472.00	0.0000	No unit root
Industrial Sector DD	−44.55	0.0000	−41.36	0.0000	1347.01	0.0000	1420.98	0.0000	No unit root
Residential Sector DD	−43.28	0.0000	−47.17	0.0000	1548.94	0.0000	1760.68	0.0000	No unit root
Transportation Sector DD	−35.84	0.0000	−35.34	0.0000	1091.86	0.0000	1128.59	0.0000	No unit root
Transportation Sector Price	−12.87	0.0000	−21.79	0.0000	638.30	0.0000	856.15	0.0000	No unit root
Commercial Sector Price	−11.94	0.0000	−11.75	0.0000	317.43	0.0000	719.04	0.0000	No unit root
Industrial Sector Price	−7.51	0.0000	−14.76	0.0000	409.38	0.0000	770.52	0.0000	No unit root
Residential Sector Price	−9.67	0.0000	−10.93	0.0000	293.65	0.0000	671.76	0.0000	No unit root
Per Capita GDP	−8.20	0.0000	−9.15	0.0000	251.74	0.0000	485.99	0.0000	No unit root

NB: All unit root tests were conducted for the variables in logs

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4.2. Long-run speed of adjustments to equilibrium

The PMG model was estimated after testing for unit roots of relevant variables of the four-sector model. The results for the commercial and industrial sectors are presented in Table 5 while the results for residential and transportation are presented in Table 6. We first compare the long-run speed of adjustment coefficients across the sectors. The speed of adjustment coefficient was −0.43, −0.41 −0.55 and −0.37 for the commercial, industrial, residential and transportation sectors, respectively. The negative values of these coefficients suggest that long-run relationships exist among the variables in each of the sectors. This implies that the four sectors adjust at a speed of 43%, 41% 55% and 37% annually to reach a steady state in the case of an external shock. It is revealed that the fastest rate of correction is in the residential sector while the least rate of disequilibrium correction is in the transportation sector. This is possible because the main source of energy in the residential sector is electricity. Therefore, demand is more likely to come back to its equilibrium at a faster rate. Contrarily, the demand for transportation sector energy takes the slowest time to readjust to a steady state equilibrium in the case of a disequilibrium. It is easy to observe such a slow adjustment rate because consumers can make alternative decisions on transportation in the long-run if there is any shock to the equilibrium. Some of the alternatives include the decision to commute with colleagues rather than use personal vehicles, deciding to use commercial means of transportation or even opting for energy efficient means of transportation.

4.3. Energy demand price and income elasticities

The long-run own-price elasticities were −0.33, −0.19, −0.45 and −0.05 for the commercial, transportation, residential and industrial sectors, respectively. These elasticities were significant at 1% for all but the industrial sector, which was not significant. The directions of the coefficients were consistent with the "a priori" expectation (Alberini & Filippini, 2011; Ming-Feng & Tai-Hsin, 2015; Okajima & Okajima, 2013). The short-run own-price elasticities were −0.27, 0.008, −0.31 and −0.17 for the residential, transportation, industrial and commercial sectors, respectively. Except for the transportation sector, all the sectors had significant short-run own-price elasticities at 1%. These price elasticities conformed to the "a priori" expectations of economic theory. The long-run and short-run own-price elasticities ranged from −0.45 to −0.17, hence are relatively inelastic.

A 1% increase in income increased energy demand for the commercial and transportation sectors by 0.16% approximately. These are both significant at 1%. The income elasticity of energy demand in the residential sector is −0.04% and significant at 1%. This suggests that energy is an inferior good. Intuitively, this does not conform to the existing literature (Alberini & Filippini, 2011). However, our study measured the individual sectoral energy consumption as shares of the total sectoral energy consumption. With the exception of few studies such as Shaik and Osei-Agyeman (2018), majority of previous literature on energy demand did not consider the sectoral energy consumption as relative shares of each other. Hence, the negative coefficient for income in the residential sector for this study reveals that, income increases as more people get employed and work overtime. For the U.S, most people work in the industrial and commercial buildings. In that regard, increasing income will be derived from spending less time at home, leading to minimum use of energy in the residential sector.

The largest income elasticity was observed in the industrial sector with 0.23% at a significance level of 1%. With the exception of the residential sector, the direction of the income elasticities is consistent with Narayan and Smyth (2007) who found the short-run income elasticity for energy in the Middle East to be 0.17. Adom and Bekoe (2013) also found a short-run income elasticity of 0.81. The magnitudes of the income elasticities reveal a relatively inelastic nature. This confirms that energy is a normal good in the short-run. Table 7 presents a summary of the sectoral elasticities. From the elasticities obtained, short-run industrial sector prices would yield the highest price response while a price change in the transportation sector will have no demand response. In the long-run, the highest response is expected from the residential sector while the industrial sector will have no demand response to a price change.

Table 5. Pooled mean group results of commercial and industrial sector

VARIABLE	COMMERCIAL SECTOR		INDUSTRIAL SECTOR	
	Coefficient	T-statistic	Coefficient	T-statistic
LONG RUN EQUATION				
Industrial Sector Energy DD	−0.0162	−0.74		
	(0.0219)			
Residential Sector Energy DD	−0.5196***	14.16	0.1023	−1.48
	(0.0367)		(0.0694)	
Transportation Sector Energy DD	0.0663**	2.01	0.0894*	1.66
	(0.0330)		(0.0539)	
Commercial Sector Energy DD			−0.1828***	−4.54
			(0.0403)	
Transportation Sector Energy Price	−0.0471***	−3.24	−0.0123	−0.50
	(0.0145)		(0.0243)	
Commercial Sector Energy Price	−0.3268***	−9.27	−0.1795**	−3.28
	(0.0353)		(0.0547)	
Industrial Sector Energy Price	−0.0336**	1.99	−0.0446	−1.53
	(0.0169)		(0.0292)	
Residential Sector Energy Price	0.1942***	4.86	−0.1126*	−1.81
	(0.0399)		(0.0622)	
SHORT-RUN EQUATION				
Speed of Adjustment Coefficient	−0.4270***	−12.77	−0.4081***	−16.64
	(0.0334)		(0.0245)	
Industrial Sector Energy DD	−0.0822***	−2.63		
	(0.0312)			
Residential Sector Energy DD	0.2997***	−11.40	0.1458***	3.27
	(0.0263)		(0.0447)	
Transportation Sector Energy DD	0.0056***	0.19	0.1462***	4.38
	(0.0293)		(0.0334)	
Commercial Sector Energy DD			−0.0629	−1.06
			(0.0594)	
Transportation Sector Energy Price	0.0304*	1.63	0.1942***	10.79
	(0.0187)		(0.0180)	
Commercial Sector Energy Price	−0.1690*** (0.0489)	−3.46	−0.0014 (0.0472)	0.30
Industrial Sector Energy Price	−0.0678*	−1.90	−0.3094***	−8.45
	(0.0355)		(0.0366)	
Residential Sector Energy Price	0.1728***	3.26	0.1504***	2.69
	(0.0529)		(0.0558)	
Per Capita Income	0.1636***	8.86	0.2281***	7.58
	(0.0185)		(0.0301)	
Technology	0.0008*	−1.23	−0.0024*	−1.88
	(0.0007)		(0.0013)	
Period Two Energy Policy Dummy	−0.0017	−0.21	−0.0320***	−3.33
	(0.0081)		(0.0096)	
Period Three Energy Policy Dummy	−0.0010	0.09	−0.0631***	−4.78
	(0.0116)		(0.0132)	

(*Continued*)

Table 5. (*Continued*)

VARIABLE	COMMERCIAL SECTOR		INDUSTRIAL SECTOR	
	Coefficient	T-statistic	Coefficient	T-statistic
Constant	0.6892	6.53	3.3713	11.48
	(0.1056)		(0.2938)	
Mean Dependent Variable (S.D.)	0.0190 (0.0648)		0.0012 (0.0828)	
S.E. of Regression (SS Residual)	0.0388 (2.374)		0.0543 (4.6534)	
Akaike Info Criterion	−3.6338		−2.8764	
Schwarz Criterion	−2.0049		−1.2475	
Hannan-Quinn Criterion	−3.0387		−2.2813	
Log Likelihood	4642.75		3806.58	

4.4. Technological change and energy demand

The results in Tables 5 and 6 also reveal the effect of technological change on energy demand in the four sectors. The effect of technological change in sectoral energy demand can be viewed in two dimensions. Technological improvements are meant to increase efficiency of either output or input. Technological improvements in the industrial sector will aid the improvement of production. In spite of this, it depends on the nature and type of technological improvements, as well as the sub-sector. For instance, technological innovations can have different energy usage impacts in manufacturing, mining, construction, agriculture, forestry and fishing. However, individual sub-sector effects may cancel out in the aggregate, leading to higher energy usage as shown from the results. In the residential and transportation sectors, technological improvements are mostly aimed at reducing energy use. The results from this study show some level of improvement in the efficiency of energy use due to technological advancement in the industrial sector. The elasticity due to technological change is −0.002% at a 10% significance level. In the transportation sector, a 1% increase in technological advancement increases energy demand by 0.0017%. This is significant at 1%. Technology is not a significant factor in energy demand decisions for the residential and commercial sectors. In general, technological improvements are expected to improve efficiency of energy demand. Our results reveal mixed relationships among the sectors. We find from the results that advances in technology had a negative coefficient (positive impact) on energy demand in the industrial sector. This implies that increases in technology led to a reduction in energy demand in this sector over the period. Technological improvements in the transportation sector also led to an increase in energy demand over the period.

Ideally, technological improvement is expected to have an effect on energy demand. The U.S Department of Energy (2010) suggested some forms of emerging technology that could help reduce energy consumption. Their report cited LED lighting, improvements in heating and cooling systems, variable refrigerant flow split systems, green/vegetated roofing and renewables among others. However, obtaining such data was difficult for our study at the aggregate level over the period. Hence, our decision to use the measure of technology suggested by Popp (2001).

5. Conclusions

The importance and consumption of energy has increased drastically in our daily lives over the years. Essentially, it has become a component of our everyday life as a way of improving productivity and human development. However, the increased consumption of energy is associated with increased greenhouse gas (GHG) emissions that may be harmful to the existence of humanity. Considering this, world leaders have sought for alternative ways to curb these emissions. The need to improve the energy consumption efficiency has become paramount among the alternatives. The U.S is the second major consumer of energy and provides several incentives to motivate the efficient consumption of energy among its populace. The objective of this study is to examine the relative price elasticities

Table 6. Pooled mean group results of residential and transportation sector

VARIABLE	RESIDENTIAL SECTOR		TRANSPORTATION SECTOR	
	Coefficient	T-statistic	Coefficient	T-statistic
LONG RUN EQUATION				
Transportation Sector Energy DD	−0.0923***	3.67		
	(0.0251)			
Commercial Sector Energy DD	−0.4598	19.81	0.0469	1.47
	(0.0232)		(0.0320)	
Industrial Sector Energy DD	−0.0545***	3.13	−0.0772***	2.65
	(0.0174)		(0.0291)	
Residential Sector Energy DD			−0.0084	−0.16
			(0.0510)	
Transportation Sector Energy Price	−0.0165	1.37	−0.1936***	−9.88
	(0.0120)		(0.0196)	
Commercial Sector Energy Price	0.2292***	8.14	−0.0157	0.42
	(0.0282)		(0.0374)	
Industrial Sector Energy Price	0.1201***	7.37	−0.1499***	6.21
	(0.0163)		(0.0241)	
Residential Sector Energy Price	−0.4465***	−13.26	−0.3364***	−7.38
	(0.0337)		(0.0456)	
SHORT-RUN EQUATION				
Speed of Adjustment Coefficient	−0.5507***	−14.49	−0.3657***	−20.95
	(0.0380)		(0.0175)	
Transportation Sector Energy DD	−0.0191	0.73		
	(0.0263)			
Commercial Sector Energy DD	0.2868***	10.21	0.0065	−.28
	(0.0281)		(0.0232)	
Industrial Sector Energy DD	0.0420**	1.90	0.0660***	4.46
	(0.0221)		(0.0148)	
Residential Sector Energy DD			−0.0748***	3.72
			(0.0200)	
Transportation Sector Energy Price	0.0365***	2.98	0.0083	0.95
	(0.0123)		(0.0087)	
Commercial Sector Energy Price	−0.0667***	2.01	−0.0155	−0.60
	(0.0333)		(0.0257)	
Industrial Sector Energy Price	−0.0448***	−2.49	−0.0369***	−2.78
	(0.0180)		(0.0132)	
Residential Sector Energy Price	−0.2690***	−6.40	0.0806*	0.01
	(0.042)		(0.0319)	
Per Capita Income	−0.0396***	3.15	0.157***	9.78
	(0.0126)		(0.0160)	
Technology	0.0004	0.62	0.0017***	2.63
	(0.0006)		(0.0007)	
Period Two Energy Policy Dummy	−0.0116*	−1.86	−0.0120*	−1.88
	(0.0062)		(0.0064)	
Period Three Energy Policy Dummy	−0.0033	0.49	−0.0035	0.48
	(0.0068)		(0.0073)	

(*Continued*)

Table 6. (*Continued*)

VARIABLE	RESIDENTIAL SECTOR		TRANSPORTATION SECTOR	
	Coefficient	T-statistic	Coefficient	T-statistic
Constant	2.5130	11.49	2.7856	17.05
	(0.2187)		(0.1634)	
Mean Dependent Variable (S.D.)	0.0100 (0.0548)		0.0119 (0.0438)	
S.E. of Regression (SS residuals)	0.0339 (1.8080)		0.0353 (1.9624)	
Akaike Info Criterion	−3.6979		−3.6656	
Schwarz Criterion	−2.0690		−2.0367	
Hannan-Quinn Criterion	−3.1028		−3.0705	
Log Likelihood	4713.46		4677.85	

Table 7. Summary of Elasticities

Sector	Short-run Own-price	Long-run Own-price	Income	Policy Period Two	Policy Period Three
Transportation Sector	0.0083	−0.1939***	0.1570***	−0.0120*	−0.0035
Commercial Sector	−0.169***	−0.3268***	0.1636***	−0.0017	−0.0010
Industrial Sector	−0.3094***	−0.0446	0.2281***	−0.0320***	−0.0631***
Residential Sector	−0.2690***	−0.4465***	−0.0396***	−0.0116*	0.0033

among the four main energy consumption sectors in the U.S. Understanding the relative price elasticities is important for policy makers to formulate price policies in the relevant sectors to contract energy consumption. A quantitative analysis hinged on the pooled mean group model was conducted using relevant data to shed more light on the energy consumption patterns and demand responses across the four U.S energy consumption sectors.

Based on the econometric model, the speed of adjustment to long-run equilibrium was obtained for each of the sectors and compared. The differences in energy consumption among these sectors depend on prices, income and technological change. All these variables are embedded in the country's energy policy framework. Hence, this study examined the price, income, and technological elasticities among the four sectors. The residential sector readjusts to long-run equilibrium at a faster rate than the other three sectors. Its long-run adjustment coefficient was 55%. This was followed by the commercial sector which readjusts at a rate of 43% while the industrial sector has a rate of 41%. The sector with the least response to disequilibrium was the transportation sector which had an adjustment coefficient of 37%.

The short-run own-price elasticity is highest for the industrial sector at −0.31, followed by the residential sector with −0.27 and −0.17 for the commercial sector. The short-run own-price elasticity for the transportation sector was not significant. This reveals that price changes do not alter the demand in this sector. Price policies in this sector to stimulate or contract energy will not be relevant. Price policies in the industrial sector directed to short-run adjustments are likely to yield desired results considering the high short-run own-price elasticities. This is because most industries keep more than one source of energy and hence easily switch to alternative sources under unfavorable conditions. According to the EIA, manufacturers use several sources of energy. These are electricity, liquified petroleum gas, coal, natural gas, agricultural waste and biofuels.

The long-run price elasticities were found to be significant for all but the industrial sector. In the long-run, a 1% increase in the price of energy in the commercial sector will lead to a 32.68% decline in energy demand. The long-run own-price elasticity for the residential sector indicates that a 1% increase in the own-price of energy in the residential sector will decrease demand by 44.65%. For the transportation sector, a 1% increase in the own-price of energy will lead to a 19.36% decline in the demand in the long-run.

In summary, the significant long-run price elasticities of the commercial, residential and transportation sectors imply that pricing policies can be used to alter long-run consumption. For short-run changes to energy consumption, it will be more rewarding to consider the commercial, industrial and residential sectors. Finally, we conclude that the residential sector readjusts to long-run equilibrium at a faster rate than the three other sectors. In the long-run, this sector will yield a higher response to a price increase. It is suggested that price policies aimed at reducing demand should primarily target the residential, followed by the commercial and transportation sectors. We acknowledge that measuring the effects of technological change on energy demand as a trend may mask some salient information and admit that measuring technological change in other forms could have had a different implication on the effect of technology in this study. However, we measured it as a trend due to limitations on the current available data. Hence, we suggest that future studies should focus on a different approach to measure technological change.

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Author details
Kwame Asiam Addey
E-mail: kwame.addey@ndus.edu[1]
Saleem Shaik
E-mail: saleem.shaik@ndus.edu[1]
Kekoura Sakouvogui
E-mail: sakouvoguikekoura@yahoo.com[2]
[1] North Dakota State University, Center for Agric. Policy and Trade Studies, Fargo, USA.
[2] Mathematical Statistician, U.S Census Bureau, Washington, DC, USA.

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Notes
1. The Paris Agreement's long-term goal is to keep the increase in global average temperature to well below 2°C above pre-industrial levels; and to limit the increase to 1.5°C. This information is available of the UNFCCC policy document found on https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf
2. See Federal Energy Regulatory Commission Staff report of 2009 for details of EISA (2007) demand response mandate.
3. Federal Energy Regulatory Commission https://www.ferc.gov/legal/staff-reports/06-09-demand-response.pdf
4. Similar applications of the PMG model to previous energy studies include Asafu-Adjaye, Byme, and Alvarez (2016) and Gautam and Paudel (2018).
5. From his review of the U.S. energy system in transition, he explained that total primary energy consumption per capita peaked before the two oil crises of the 1970s and declined in response to them. Irregular growth resumed from a low in 1983 to reach another peak in 2000 (3% lower than the peak of 1979) before beginning a long but uneven decline of 14% through 2017. See his paper listed in the reference for an in-depth description of the transitions over the period.

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The views from this article are those of the authors and not that of their respective institutions.

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