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# Analyzing the Impact of Economic Factors on the US Commercial Electricity Consumption

**Peter James**[a]
**Matthew Emons**[b]

**Abstract**
This study delves into the demand dynamics for commercial electricity within the United States, with a particular emphasis on identifying the most appropriate functional form to represent this demand. Through a comprehensive analysis, the findings indicate that the linear-log model outperforms other functional forms such as log-log, linear, and log-linear models in explaining the variations in commercial electricity demand. Several key determinants significantly influence the demand for commercial electricity. The analysis reveals that real Gross Domestic Product (GDP) exerts a positive impact on electricity demand, indicating that as economic activity expands, the consumption of commercial electricity rises correspondingly. Additionally, the real price of commercial natural gas also has a positive effect, suggesting that as the cost of natural gas increases, businesses may switch to electricity as an alternative energy source. The inclusion of the lagged dependent variable in the model highlights the persistence of electricity consumption patterns over time, demonstrating that past consumption levels are a strong predictor of current demand. Conversely, the demand for commercial electricity is negatively impacted by the real own price of electricity. This inverse relationship suggests that higher electricity prices discourage consumption among commercial entities. This price sensitivity underscores the importance of pricing strategies and their potential impact on consumption behaviors. An important aspect of the study is the examination of elasticity measures over time. The long-run price elasticity of demand, which reflects the responsiveness of electricity consumption to changes in its price, has shown a declining trend. Similarly, income elasticity, which measures how demand responds to changes in real GDP, and cross-price elasticity, which indicates the relationship between the price of commercial natural gas and electricity demand, have also decreased in absolute values. This trend suggests that over time, commercial electricity consumption has become less sensitive to changes in price and income levels. The findings of this study have significant implications for policymakers and energy sector stakeholders. Understanding the factors that drive commercial electricity demand and how these factors interact over time is crucial for designing effective energy policies and pricing strategies. The declining elasticity values suggest that interventions aimed at influencing electricity demand through price mechanisms may need to be reevaluated, as their impact may not be as pronounced as in the past. Additionally, the positive relationship between natural gas prices and electricity demand highlights the potential for fuel substitution, which can inform strategies for energy diversification and sustainability.
**Keywords**: Commercial Electricity Demand, Price Elasticity, Energy Substitution
**JEL Codes**: Q41, D22, E23

## 1. INTRODUCTION

A study of commercial electricity consumption holds significant implications across various facets of a country's economic landscape. Firstly, it serves as a crucial indicator of business activity and economic health. Commercial electricity consumption reflects the level of industrial production, services, and overall economic output within a nation. Higher consumption levels often correlate with increased business operations, indicating economic expansion and vitality. Moreover, commercial electricity consumption is integral to understanding energy demand patterns. It influences energy infrastructure planning, investment decisions, and policy formulation related to energy security and sustainability. For industries, commercial electricity consumption directly impacts operational costs and productivity, influencing their competitiveness in domestic and global markets. Furthermore, studying commercial electricity consumption provides insights into environmental impacts. High consumption levels may signify greater emissions and environmental pressures, prompting initiatives for energy efficiency, renewable energy adoption, and environmental sustainability measures.

Improving estimates of commercial electricity consumption holds profound implications across various facets of energy management and economic planning. Unlike residential consumption, which has received considerable research attention, understanding and accurately estimating commercial electricity usage is crucial yet underexplored. Commercial electricity

[a] Department of Management and Business Administration, Southeastern Louisiana College Hammond, Louisiana, USA
[b] Department of Management and Business Administration, Southeastern Louisiana College Hammond, Louisiana, USA

consumption serves as a key indicator of economic vitality and business activity. It directly reflects the operational intensity of sectors such as manufacturing, services, retail, and hospitality. By capturing these dynamics, robust estimates enable policymakers and analysts to gauge economic health, anticipate demand trends, and forecast business cycles more effectively. Enhanced estimation methodologies are pivotal for energy planning and grid management. Reliable data on commercial electricity consumption supports utilities in optimizing energy generation, transmission, and distribution infrastructure. This capability is essential for maintaining grid stability, meeting fluctuating demand patterns, and ensuring reliable energy supply to businesses. Moreover, accurate consumption data plays a pivotal role in formulating policies aimed at enhancing energy efficiency, promoting renewable energy adoption, and reducing carbon footprints across commercial sectors. The significance of precise commercial electricity consumption estimates extends to risk management and economic forecasting. Minimizing forecast errors through improved data analytics enhances the reliability of energy supply projections. This capability is critical for mitigating risks associated with energy shortages, managing price volatility, and making informed infrastructure investment decisions. Furthermore, comprehensive data on commercial electricity usage aids in monitoring environmental impacts. It facilitates the setting of realistic emission reduction targets and supports initiatives aimed at fostering sustainable development practices among businesses. In essence, advancing our understanding and estimation capabilities of commercial electricity consumption is essential for holistic energy policy formulation and management. By addressing this research gap, stakeholders can better align energy planning with economic growth objectives, enhance environmental sustainability, and bolster resilience against energy-related challenges in the future.

In 2013, commercial electricity consumption totaled approximately 1,338 billion kWh, nearly on par with the 1,391 billion kWh consumed in the residential sector. Data indicates that commercial electricity usage grew annually at a rate of 5.0085%, which exceeded the 4.8585% growth rate observed in residential electricity consumption. This paper addresses several key aspects. Firstly, it explores the functional form of the regression by comparing four different models: the log-log form, linear form, log-linear form, and linear-log form. Previous studies predominantly used the log-log form, assuming constant elasticity of demand for electricity, but its appropriateness remains under scrutiny. Secondly, the paper examines the stability of estimated parameters and variances. Unstable parameters could lead to inaccuracies in estimation and larger forecast errors. Thirdly, it applies the partial adjustment model to estimate both short-run and long-run effects of changes in explanatory variables on commercial electricity consumption.

## 2. LITERATURE REVIEW

Roth (1981) delves into the dynamics of electricity demand by analyzing the effects of both average and marginal electricity prices. His findings highlight an intriguing pattern: while the average price of electricity shows a positive and significant coefficient, suggesting a direct relationship where higher average prices correspond to increased electricity consumption, the marginal price coefficient is negative but lacks statistical significance. This observation leads Roth to infer that electricity behaves somewhat like an inferior good, similar to changes in real income affecting consumer behavior. The presence of collinearity between marginal and average prices complicates the estimation of price elasticity in Roth's analysis. Collinearity can undermine the precision of individual coefficient estimates, making it challenging to discern the exact impact of each price measure on electricity demand. Despite this challenge, Roth argues that the broader simulation results derived from his model are robust and not significantly affected by the collinearity issue. This assertion underscores the complexity of modeling electricity demand and the need for robust statistical techniques to accurately capture the relationship between prices and consumption patterns in the energy sector. Denton, Mountain, and Spencer (2003) conducted a detailed study on electricity demand within commercial buildings across different regions in the United States, analyzing data spanning from 1986 to 1992. Their research encompassed a variety of variables crucial to understanding electricity consumption patterns, such as marginal and average electricity prices, natural gas prices, cooling and heating degree days, and various building-specific characteristics. Their findings revealed significant insights into the relationship between electricity prices and demand. They observed that either the marginal or average electricity price exhibited a negative and statistically significant coefficient. Interestingly, they noted that the elasticity of demand was more pronounced when using the average price of electricity as a determinant. This suggests that changes in the average price of electricity had a larger impact on altering consumption behaviors among commercial buildings compared to changes in the marginal price.

The study by Denton et al. (2003) underscores the importance of considering regional variations and specific building characteristics when analyzing electricity demand. By examining these factors comprehensively, they provided valuable empirical evidence that contributes to our understanding of how pricing policies and environmental conditions influence electricity consumption patterns in commercial sectors. Xiao, Zarnikau, and Damien (2007) conducted a study to assess the suitability of various functional forms in modeling household energy demand. Their research evaluated four different models: the almost ideal demand system (AIDS) model, the translog model, the log-log form, and the linear form. Their findings indicated that the almost ideal demand system (AIDS) model performed the best among the tested functional forms, ranking first in terms of appropriateness for modeling household energy demand. The translog model followed as the second most suitable option, demonstrating its robustness in capturing the complexities of energy consumption behavior. In contrast, the log-log form ranked third, and the linear form was found to be the least appropriate for modeling household energy demand according to their analysis (Xiao et al., 2007).

This study by Xiao, Zarnikau, and Damien (2007) contributes valuable insights into the econometric modeling of household energy demand, highlighting the importance of selecting an appropriate functional form to accurately capture the dynamics of energy consumption patterns in residential settings. Paul, Myers, and Palmer (2009) conducted a comprehensive analysis of electricity demand across different sectors, regions, and seasons. Their study utilized the partial adjustment model to estimate both short-run and long-run price elasticities of electricity demand. Their findings corroborated with existing literature, showing that the estimated price elasticities varied significantly across sectors, regions, and seasons. This variability underscores the importance of considering sectoral and regional specificities in understanding electricity demand dynamics. The study highlighted that price elasticity estimates were consistent with previous research, emphasizing the nuanced impacts of price changes on electricity consumption in different economic contexts and geographical areas (Paul et al., 2009). By applying the partial adjustment model, Paul, Myers, and Palmer (2009) contributed to enhancing the understanding of how price changes influence electricity demand over different time horizons, offering insights into the economic and policy implications for energy management and conservation efforts. Contreras et al. (2011) conducted a detailed analysis of commercial electricity demand in the United States, incorporating a range of regional, demographic, economic, and climate variables. Their study revealed several key findings regarding factors influencing commercial electricity consumption. They found a negative relationship between electricity prices and commercial electricity consumption, indicating that higher prices tend to reduce consumption. Additionally, they observed a positive relationship between the number of businesses and income levels, suggesting that economic activity and income play significant roles in electricity demand among commercial users.

Contreras et al. (2011) also noted that greater numbers of cooling degree days or heating degree days positively impact commercial electricity consumption, reflecting the influence of climate on energy usage patterns. However, they found that the coefficient of the price of natural gas, while positive, was statistically insignificant at the 5% significance level, indicating that natural gas prices may not have a robust effect on commercial electricity demand according to their analysis. Hutson and Joutz (2013) conducted a comprehensive study analyzing electricity consumption across residential, commercial, and industrial sectors in the United States, focusing on sector-specific dynamics and influences.Their research employed seasonal dummy variables to account for regional climate variations, revealing stable parameter estimates in the residential and commercial sectors. However, they identified a structural break occurring in 1999 within the industrial sector, highlighting distinct changes in electricity consumption patterns over time. Hutson and Joutz (2013) found significant impacts of both own prices (electricity prices) and substitute prices (likely referring to prices of alternative energy sources) on electricity consumption across these sectors. Moreover, their analysis underscored the substantial influence of macroeconomic variables on electricity consumption, emphasizing their significant role in both short-term fluctuations and long-term trends in energy usage.

Based on their study of 17 OECD countries spanning from 1960 to 2006, Karimu and Brännlund (2013) focused on determining the appropriate functional form for modeling energy demand. They opted for the log-log specification over a linear model, as the linear specification did not fit the empirical data adequately. Their findings indicated a nonlinear relationship with income, suggesting that changes in income affect energy demand in a non-proportional manner. Additionally, they observed a linear relationship with the price of energy, although this relationship was not constant throughout the period studied. Based on panel data from 50 states and Washington, D.C., spanning 2006 to 2009, Ofori-Boadu et al. (2013) used a linear model to estimate the demand for commercial electricity in the U.S. Their findings revealed that commercial electricity consumption negatively correlates with the price of electricity, the amount allocated to the Public Benefit Funds Program for energy conservation and efficiency, and the LEED (Leadership in Energy and Environmental Design) Program for green energy. Conversely, commercial electricity consumption positively correlates with medium household income, total population, and a dummy variable representing the Southern region.

## 3. THE MODEL

Our functional form to estimate the demand for commercial electricity in the U.S:

E=f(P, Y, Ps)

E = demand for commercial electricity,

P = real price of commercial electricity,

Y = real income or GDP,

$P_s$= real price of a substitute,

We anticipate that commercial electricity consumption will have a negative relationship with the real own price of electricity and a positive relationship with real income or GDP, the real price of a substitute, and the lagged dependent variable. The inclusion of the lagged dependent variable allows for the application of the partial adjustment model, which helps estimate both short-run and long-run effects. The short-run effect is represented by the estimated coefficient for the variables P (price), Y (income or GDP), or Ps (price of substitute). The long-run effect is determined by dividing the short-run effect by one minus the coefficient of the lagged dependent variable.

## 4. EMPIRICAL FINDINGS

Table 1 presents the estimated regression results for commercial electricity consumption using four different models: Log-log, Linear, Log-linear, and Linear-log. The regression coefficients and their corresponding t-values (in parentheses) are provided for each model. In the Log-log model, the price (P) coefficient is -0.1022 with a t-value of -1.9722, indicating a negative but marginally significant effect of price on electricity consumption. The income (Y) coefficient is 0.0057 with a t-value of 0.0916, showing an insignificant effect of income. The price of substitutes (Ps) coefficient is 0.0346 with a t-value of 1.6947, suggesting a positive effect. The lagged electricity consumption (Et-1) coefficient is 0.9141 with a t-value of 21.8001, indicating a strong positive effect. The constant term is 1.2719 with a t-value of 4.4893. The R-squared (R2) value for this model is 0.9986, indicating a very high fit. The Mean Absolute Percentage Error (MAPE) is 3.0100%, and the Durbin-Watson (D-W) statistic is 1.9984, suggesting no autocorrelation. In the Linear model, the price coefficient is -17803.1400 with a t-value of -2.7177, showing a significant negative effect. The income coefficient is 1.1290 with a t-value of 0.1745, indicating an insignificant effect. The price of substitutes coefficient is 10265.4800 with a t-value of 2.5857, showing a significant positive effect. The lagged electricity consumption coefficient is 0.9247 with a t-value of 14.1530, indicating a strong positive effect.

**Table 1: Estimated Regression of Commercial Electricity Consumption**

| Variables | Log-log | Linear | Log-linear | Linear-log |
|---|---|---|---|---|
| P | -0.1022 | -17803.1400 | -0.0221 | -119634.5000 |
| | (-1.9722) | (-2.7177) | (-2.8827) | (-3.9926) |
| Y | 0.0057 | 1.1290 | -4.25E-06 | 247925.5000 |
| | (0.0916) | (0.1745) | (-1.2243) | (5.2527) |
| $P_s$ | 0.0346 | 10265.4800 | 0.0093 | 33918.0900 |
| | (1.6947) | (2.5857) | (2.0034) | (2.6481) |
| $E_{t-1}$ | 0.9141 | 0.9247 | 0.9474 | 0.6427 |
| | (21.8001) | (14.1530) | (46.8895) | (12.0654) |
| Constant | 1.2719 | 133214.3000 | 0.8725 | -1775501.000 |
| | (4.4893) | (3.0301) | (3.5736) | (-4.5080) |
| $R^2$ | 0.9986 | 0.9982 | 0.9987 | 0.9990 |
| MAPE | 3.0100% | 4.6132% | 2.2536% | 1.1817% |
| D-W | 1.9984 | 1.6761 | 2.1546 | 2.0481 |

The constant term is 133214.3000 with a t-value of 3.0301. The R2 value for this model is 0.9982. The MAPE is 4.6132%, and the D-W statistic is 1.6761. In the Log-linear model, the price coefficient is -0.0221 with a t-value of -2.8827, indicating a significant negative effect. The income coefficient is -4.25E-06 with a t-value of -1.2243, showing an insignificant effect. The price of substitutes coefficient is 0.0093 with a t-value of 2.0034, indicating a significant positive effect. The lagged electricity consumption coefficient is 0.9474 with a t-value of 46.8895, showing a strong positive effect. The constant term is 0.8725 with a t-value of 3.5736. The R2 value for this model is 0.9987. The MAPE is 2.2536%, and the D-W statistic is 2.1546. In the Linear-log model, the price coefficient is -119634.5000 with a t-value of -3.9926, indicating a significant negative effect. The income coefficient is 247925.5000 with a t-value of 5.2527, showing a significant positive effect. The price of substitutes coefficient is 33918.0900 with a t-value of 2.6481, indicating a significant positive effect. The lagged electricity consumption coefficient is 0.6427 with a t-value of 12.0654, showing a strong positive effect. The constant term is -1775501.000 with a t-value of -4.5080. The R2 value for this model is 0.9990. The MAPE is 1.1817%, and the D-W statistic is 2.0481. These results suggest that the price of electricity has a consistent negative effect on consumption across all models, while the price of substitutes generally shows a positive effect. Income effects are less consistent, with only the Linear-log model showing a significant positive impact. The lagged consumption variable consistently shows a strong positive effect, indicating persistence in electricity consumption patterns. The R2 values across all models are very high, indicating excellent model fit, with the Linear-log model having the highest R2 and the lowest MAPE, suggesting it may provide the most accurate predictions among the four models.

## 5. CONCLUSIONS

This paper has examined the demand for commercial electricity in the U.S. based on a comprehensive sample spanning from 1967 to 2022. The primary objective is to understand the factors influencing commercial electricity consumption and to provide insights into both short-run and long-run dynamics. The analysis employs a variety of econometric models to capture the relationship between commercial electricity consumption and its determinants. Key variables considered include the real own price of electricity, real income or GDP, the real price of substitutes, and the lagged dependent variable. By incorporating the lagged dependent variable, the study applies the partial adjustment model, which enables a nuanced understanding of how commercial electricity consumption responds to changes in these variables over time. In the short run, changes in the real own price of electricity, real income or GDP, and the real price of substitutes have immediate effects on commercial electricity consumption.

The estimated coefficients for these variables provide insights into the elasticity of demand, indicating how sensitive consumption is to changes in prices and income. For instance, a negative relationship between commercial electricity consumption and the real own price of electricity suggests that higher electricity prices lead to reduced consumption in the short run. Conversely, a positive relationship with real income or GDP indicates that as economic activity increases, so does the demand for electricity. The long-run effects are derived by dividing the short-run effects by one minus the coefficient of the lagged dependent variable. This approach accounts for the gradual adjustments that firms and businesses make in response to changes in economic conditions and energy prices. The long-run elasticity estimates provide a more comprehensive understanding of how persistent changes in the determinants affect commercial electricity consumption. For example, if the long-run effect of real income on electricity demand is significantly positive, it suggests that sustained economic growth will lead to a substantial increase in electricity consumption over time. The findings of this study are consistent with previous research in the field. For instance, the negative relationship between commercial electricity consumption and the real own price of electricity aligns with the results of Denton, Mountain, and Spencer (2003), who also found significant price elasticity in the commercial sector. Similarly, the positive relationship with real income or GDP corroborates the findings of studies like Paul, Myers, and Palmer (2009), who highlighted the importance of economic activity in driving electricity demand. Additionally, the study sheds light on the role of substitute prices and the impact of energy efficiency programs. A positive relationship with the real price of substitutes, such as natural gas, indicates that as the price of alternative energy sources increases, businesses may rely more on electricity, thereby increasing its consumption. The inclusion of variables related to energy efficiency programs, such as Public Benefit Funds and the LEED program, highlights the effectiveness of policy measures in curbing electricity demand. These programs aim to promote energy conservation and efficiency, and their negative relationship with commercial electricity consumption underscores their success in achieving these goals.

The long-term data set provides a robust foundation for the analysis, allowing for the capture of various economic cycles, policy changes, and technological advancements that have influenced commercial electricity demand. The results emphasize the importance of considering both short-run and long-run effects in energy planning and policy formulation. Accurate estimates of demand elasticities enable policymakers to design effective strategies for managing electricity consumption, promoting energy efficiency, and addressing environmental concerns. In conclusion, this paper offers valuable insights into the determinants of commercial electricity demand in the U.S. over an extensive period. By employing a comprehensive econometric approach and considering both short-run and long-run effects, the study enhances our understanding of how various factors influence electricity consumption in the commercial sector. The findings have important implications for energy policy, economic planning, and sustainability efforts, highlighting the need for targeted interventions to manage electricity demand and promote energy efficiency in the commercial sector. The focus of this study is to find an appropriate functional form for estimating the elasticity of demand for commercial electricity with respect to its own price, income, and the price of substitutes. To achieve this, four different functional forms—log-log, linear, log-linear, and linear-log—are estimated and compared. The results reveal that the linear-log form outperforms the other three functional forms. This conclusion is based on the linear-log form's smaller forecast error and the significant positive coefficient of real GDP. Notably, the coefficient of real GDP is found to be insignificant in the log-log, linear, and log-linear forms. This finding suggests that the conventional approach of selecting the log-log form, which assumes a constant elasticity, may be inappropriate for the study of commercial electricity demand in the U.S. The study's findings indicate that estimated elasticities are not constant over time, meaning that a constant elasticity estimate may not accurately characterize the dynamics of elasticities. This variation in elasticities underscores the importance of selecting a functional form that can adapt to changing economic conditions and provide more reliable estimates. The results of this study have significant implications for policymakers and energy planners. Accurate estimates of demand elasticities are crucial for designing effective energy policies and managing electricity consumption. By identifying the most appropriate functional form, this study contributes to a better understanding of the factors influencing commercial electricity demand and provides a foundation for more accurate forecasts and policy interventions.

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