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Price elasticities of retail energy demands in the United States: New evidence from a panel of monthly data for 2001–2016

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HIGHLIGHTS

- Propose a Generalized Leontief system of retail energy demands by customer class.
- Comprehensively estimate retail energy demands' price responsiveness in the USA.
- Document highly price-inelastic retail energy demands.
- Reason that DSM helps achieve a clean and sustainable energy future in the USA.

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ABSTRACT

Price elasticities play an important role in energy demand forecasting, which in turn shapes energy policy and investment decisions. However, there is still considerable debate around how responsive customers are to energy prices, and whether investments in metering and consumer education have made them more responsive in recent decades. Using a Generalized Leontief (GL) demand system and a rich panel of monthly data covering 2001–2016 for the lower 48 United States, we estimate own- and cross-price elasticities of retail demand for electricity, natural gas and fuel oil for the three major customer classes: residential, commercial and industrial. These estimates indicate that retail energy demand in the United States was highly price-inelastic over 2001–2016, consistent with historical and current estimates used by many utility planners. Our findings suggest that, with current technologies and behavior, higher energy prices will not induce significant reductions in demand. Hence, energy efficiency standards and utility demand-side programs are still an important strategy for managing energy demand growth, mitigating energy price risk, and reducing the environmental impacts associated with energy use. Finally, while our analysis uses data from the United States, our approach is general and can be readily extended to other countries that have similar data available.

1. Introduction

Energy demand growth projections are necessary for energy policy modeling [1] and resource planning [2,3]. Following [1,p.5], an intuitive representation of a growth projection is the sum of: (a) the demand change due to price changes; (b) the demand change due to changes in such non-price factors as income and appliance stock; and (c) the demand change attributable to demand-side management (DSM) initiatives (e.g., a government's energy efficiency (EE) standards and an electric utility's DSM programs [4]).

This paper focuses on price-induced changes in demand (a). Eq. (1) below shows that a price-induced demand change can be calculated as:

$$\Delta Q_t = Q_{t-1} \sum_m \varepsilon_m \ln(W_{mt}/W_{mt-1}), \tag{1}$$

where ΔQ_t = demand change over one period; Q_{t-1} = demand in period $t-1$; ε_k = demand price elasticity with respect to the m^{th} price W_m; and $\ln(W_{mt}/W_{mt-1})$ = percent change in W_m over one period. For clarity, we use the first price W_1 to denote the own-price and $\varepsilon_1 < 0$ to denote the own-price elasticity. If W_m is the price of a substitute (complement), the cross-price elasticity ε_m is positive (negative).

To appreciate the real-world significance of price elasticities,

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consider an electric utility that is planning to meet its customer demand over the next 10 years and forecasts sustained increases in electricity prices due to the cost of complying with a renewable portfolio standard (RPS). If customers are price inelastic, the utility will need to procure more renewable generation to comply with the RPS. If customers are more price elastic, the utility can procure less renewable generation and still comply. If the utility uses an inaccurate price elasticity estimate, it will over- or under-procure renewable energy, leading to excessive costs or compliance penalties. This example illustrates how price elasticity estimates used in investment planning translate into investment decisions, with implications for costs and risk allocation.

Despite the importance of price elasticities, elasticity estimates vary widely. For instance, to inform national energy policies, the U.S. Energy Information Administration (EIA) publishes an *Annual Energy Outlook* (AEO) pursuant to the Department of Energy Organization Act of 1977 [5]. Its AEO is based on the national energy modeling system (NEMS) [6], which uses price elasticity assumptions to develop energy demand growth projections [7]. For retail electricity demands, the 2017 AEO assumes a price elasticity of −0.15 for the residential class and −0.25 for the commercial class [7, Chapters 4 and 5]. Fifteen years ago, the AEO assumed a price elasticity of −0.20 for the residential class and −0.10 for the commercial class [8, Table 4].

While the 2017 AEO's elasticity assumptions resemble the −0.16 to −0.25 estimates used by the U.S. Environmental Protection Agency (EPA) [9], they sharply contrast with those adopted by some North American electric utilities. For instance, BC Hydro, which serves the Canadian province of British Columbia, uses an own-price elasticity estimate of −0.10. This estimate is comparable to the estimates used by two Pacific Northwest utilities: −0.05 to −0.15 for the residential class and −0.10 for the non-residential class [10, Table 4]. An electric cooperative in the state of Kentucky uses −0.25 for the residential class, −0.10 for the commercial class, and −0.05 for the industrial class [11]. In general, utility estimates appear to be lower than those used by federal government agencies and are consistent with a conventional assumption of inelastic demand.

Beyond regional differences in price elasticities [12], utilities' lower price elasticities may be explained by their aversion to the risk of insufficient supply. Large electricity price elasticity estimates can cause them to underestimate electricity demand growth, which may in turn lead to capacity shortages. Hence, an electric utility's elasticity assumptions reflect a tradeoff between supply capacity costs and the political and economic costs of customer outages, as explained by [13] in the context of efficient resource planning under demand and supply uncertainties.

Are higher or lower energy price elasticity estimates more consistent with recent empirical evidence? Has energy demand become more price elastic over time as a result of, for instance, more advanced metering and more consumer education around energy efficiency opportunities? To answer these questions, this paper uses a Generalized Leontief (GL) demand system [14] and a newly constructed panel of monthly data for the lower 48 United States over the 16-year period 2001–2016 to estimate price elasticities of retail energy demand for electricity, natural gas and fuel oil for three major customer classes: residential, commercial and industrial.

Our key findings are as follows. First, our electricity price elasticity estimates are closer to those used by some North American utilities, implying that electricity demand is largely unresponsive to changes in price. Second, retail electricity demand is generally less price-responsive than retail natural gas and fuel oil demand. Third, electricity and natural gas are substitutes, with small and positive cross-price elasticity estimates. Finally, retail fuel oil demands are unresponsive to changes in electricity prices though not to changes in natural gas prices.

Our empirical analysis makes three contributions to the literature on energy demand estimation. First, we use a GL demand system and a newly constructed panel of monthly data to estimate price elasticities of retail energy demand for the 48 lower United States. Our choice of the GL specification is motivated by its formal test of the hypothesis of zero substitution among the three principal energy types: electricity, natural gas and fuel oil. To the best of our knowledge, no other demand study has done a joint estimation like ours for the three major customer classes.[1]

Second, we show that retail energy demands in the United States are highly price-inelastic, more so for electricity than for natural gas and fuel oil. This finding suggests that higher energy prices—for instance, resulting from environmental regulation or higher fuel prices—will have a limited impact on energy demands. While the retail price increases will only minimally curtail energy demands, there are well-known and time-proven measures for achieving discernable demand reductions. A good case in point is that mandatory EE standards can increase the market penetration of highly energy-efficient appliances (e.g., air conditioners and water heaters with high EE ratings) that may not have been bought by some households despite escalating energy prices. Similarly, an electric utility may implement such DSM programs as energy audits, public education and financial rebates to promote energy-efficiency investments by its customers. Thus, cost-effective EE standards and DSM programs still have an important role to play in managing energy demands, mitigating energy price risk, and reducing emissions and other environmental impacts from energy use.

Finally, our method is general. It can be readily implemented in other countries with similar data availability. One case that has significant academic and policy interest is the world's largest energy consuming country, China, whose annual energy consumption data by sector and province are also publicly available.[2] To be sure, constructing a Chinese data file is by no means easy, especially in assembling suitable price data series necessary for a system estimation of energy demand. With improved data availability, however, we posit that our approach can be used for estimating the price elasticities of retail energy demand in China.

This paper proceeds as follows. Section 2 contextually links our paper to the energy demand literature, presents our GL demand system, and describes our panel data. Section 3 reports our empirical results. Section 4 concludes.

2. Material and methods

2.1. Contextual linkage

To contextually link our paper to the vast literature on energy demand estimation, this section reviews retail demand studies of electricity, natural gas and fuel oil for three customer classes: residential, commercial and industrial. As such, it is *not* a review of time series modeling of electricity loads [15,16] or the estimation of capital-labor-energy-material models [17–22]. It also excludes demand models for transportation fuels (e.g., gasoline, diesel and ethanol), which are beyond our research scope.

As there are hundreds of retail energy demand studies, we necessarily rely on extant surveys [23–31]. These surveys indicate that own- and cross-price elasticity estimates are typically developed from the data for a given type of energy (e.g., electricity or natural gas) consumed by a particular customer class (e.g., residential or commercial). Relatively rare are the price elasticity estimates found using a single large data file that encompasses multiple energy types and customer classes. This is understandable, in light of the empirical challenges in assembling such data and performing the associated estimation.

With electricity as the dominant focus of research, residential demand studies are based on the theory of consumer behavior [32].

[1] Section 2.1 below provides the contextual linkage between our paper and the large body of literature on energy demand estimation.

[2] https://china.lbl.gov/research-projects/china-energy-databook.