Estimating the Price Elasticity of Natural Gas and Electricity in Pacific Northwest

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Abstract: This paper estimates the price elasticity of electricity and natural gas in the Pacific Northwest. Electricity and natural gas are substitutes; and demands of different classes of consumers for the energy are price-inelasticity. The results are when the price of retail electricity and natural gas changes, consumers would choose the cheaper one to make up for the increased cost of another energy price. Consumers' demand for energy is mainly stable, they won't affect a lot by the change in energy prices.

1. Introduction

Electricity can be produced by fossil fuels, including natural gas, coal, and petroleum. According to the EIA, natural gas was the largest source—about 38%—of U.S. electricity generation in 2021, and both steam turbines and gas turbines can generate electricity. If the price of natural gas changes, the price of electricity will also be affected correspondingly. Knowing how changes in electricity prices affect the consumption of consumers becomes significant in the area of energy policy model (Manne et al., 1979), electric utility resource plans (Wilkerson et al., 2014), demand reponse (EPA, 2008), and so on.

This study echoes the global carbon emission reduction objective. For example, assumed 10% electricity rate increase an immaterial CO_2 emission decline of 620 to 2,786 t for the Pacific Northwest.(Woo et al., 2017). The estimated price elasticity may serve as a well-grounded justification for policy makers to implement price management policies. For instance, CMU (2011)assess the price and income elasticity for household electricity consumption in the U.S. and found that price elasticity estimates range from −0.21 to −0.25. The results confirm most previous studies that have found inelastic values for both price and income elasticity. (Azevedo et al., 2011). While another study also supported this argument that Pacific Northwest's own-price elasticity estimates are larger in size than California's (−0.0323, −0.0144, and −0.0348 for the residential, commercial, and industrial sectors), they indicate that retail electricity and natural gas demands are highly price-inelastic.(Woo et al., 2017).

For the long-run effect, a study used national-level data for a sample of 44 countries to estimate the price and income elasticities of natural gas demand. It presented both single-equation results and results instrumenting natural gas prices with proved natural gas reserves. They concluded that the long-run price elasticity of natural gas demand point estimates is around −1.25.(Burke et al., 2016).

Our exploration estimates the price elasticity of natural gas and electricity in the Pacific Northwest (Idaho, Oregon, and Washington) using monthly data from 2001.01 to 2022.08 to determine the nexus between consumption and the price of major end-use consumers for residential, commercial, and industrial purposes. Our findings are:

The following sections are organized as: Section 2 introduces methodology and background, section 3 presents key results with discussions while section 4 concludes.

2. Methodology

2.1. Regression Model

We use a CES (constant elasticity of substitution) system to estimate how the price change in retail electricity would response to the change in natural gas demand. This system was previously used to estimate how time-varying price causes peak and off-peak demand change (Woo et al., 2013a).

Suppose:

X_j = electricity consumption (GWh);
E_j = electricity price ($/GWh);
Y_j = natural gas consumption (MMcf);
G_j = natural gas price ($/MMcf);
μ_j = random errors;
α_{EGj} = marginal effect;
Z_j = a function of non-price elements.

CES system constructs the equation as:

$$\ln(X_j/Y_j) = \alpha_j + \alpha_{EGj} \ln(E_j/G_j) + Z_j + \mu_j \qquad (1)$$

(Note: Residential: j =1, Commercial: j = 2, Industrial: j = 3)

In the equation, $\ln(X_j/Y_j)$ is the natural log of class j's ratio of electricity and natural gas consumption and

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$\ln(E_j/G_j)$ is the natural log of class j's ratio of electricity and natural gas price. We predict that as α_{EGj} j will be negative, $\ln(X_j/Y_j)$ will move in the different dirctions with $\ln(E_j/G_j)$. When α_{EGj} equals to zero, the price of electricity and natural gas consumption will have no relationship with the demand.

We use Z_j to consider the elements other than price in the Pacific Northwest, including time line, real GDP, and weather variables (CDD – cooling degree days; HDD – heating degree days). In order to avoid zero values in the weather variables, we add one for each number and apply natural log – ln(CDD + 1)/ ln(HDD + 1).

The own-price elasticities of demand can be found through the CES system's price coffecients, αEGj. Since the class j's electricity demand is related to the price ratio rather than the price levels, we can calculate the own-price elasticity of electricity as

$$\varepsilon_{EEj} = \alpha_{EG} \times [G_j*Y_j/(E_j*X_j + G_j*Y_j)] \quad (2)$$

It can be seen that

$$\varepsilon_{EEj} = - \varepsilon_{EGj} \quad (3)$$

The own-price elasticity equals to the negative value of the cross-price elasticity. The absolute value of them are equal $|\varepsilon_{EEj}| = |\varepsilon_{EGj}|$.

Suppose the μ_j is correlated in the system of equations, we can consider three sections together by using ITSUR estimation (iterative seemingly unrelated regressions) in STATA and robust SE (Wooldridge, 2010).

2.2. Caculations

Suppose there's an electricity policy that makes the elecriticity price rate increase 0.1, we calculate how it will affect the consumption as following:

• Step 1. Calcualte the own-price elasticity of electricity:

$$\varepsilon_{EEj} = \alpha_{EG} \times [G_j*Y_j/(E_j*X_j + G_j*Y_j)] \quad (2)$$

• Step 2. Calcutate the change of electricity consumption in class j:

$\Delta X_j = 0.1\varepsilon_{EEj} \times$ class j's electricity consumption(GWh) (4)

($\varepsilon_{GGj} < 0, \Delta Y_j < 0$)

• Step 3. Calcutate the change of natural gas consumption in class j:

$\Delta Yj = 0.1\varepsilon GGj \times$ class j's natural gas consumption (MMcf) (5)

($\varepsilon_{GGj} < 0, \Delta Y_j < 0$)

• Step 4. Calculate the price elasticity between electricity price and natural gas demand.

2.3. Data Discription

The data of energy consumption, price and weather comes directly form the EIA (the U.S. Energy Information Administration) website from January 2001 to August 2022. The GDP data comes form BEA (an official website of the United States government) from January 2001 to June 2022.

(Note: The ending data is the latest data at the time we writing the paper.)

• The monthly electricity and natural gas consumption

• The monthly electricity and natural gas retail price data

• The monthly weather data by census region including CDD and HDD

• The monthly real GDP data. We calculate it from the quarterly GDP:

Month_j GDP = first-quarter GDP × [(Month_j employment × days)/ Month_j employment × 31 days + Month_{j+1} employment × days + Month_j employment × days)]. (6)

Table 1. ITSUR regression results of the CES system

	Residential class: (j = 1)	Commercial class: (j = 2)	Industrial class: (j = 3)
Adjusted R^2	0.9383	0.9191	0.6853
RMSE	0.1416	0.1418	0.1376
Intercept	4.2802 (2.0579)	3.5711 (2.0517)	7.3327 (1.9769)
$Ln(E_j/G_j)$	0.3957 (0.0680)	0.2101 (0.0582)	0.3584 (0.0421)
Trend	0.0021 (0.0009)	0.0018(0.0008)	0.0047 (0.0008)
Ln(GDP)	0.4472 (0.2466)	0.5666 (0.2455)	0.9645 (0.2377)
Ln(CDD+1)	0.1478 (0.0266)	0.3037 (0.0266)	0.0357 (0.0259)
Ln(HDD+1)	0.2595 (0.0266)	0.0709 (0.0262)	0.1152 (0.0254)

3. Results and Discussion

Table 1 shows the ITSUR regression results from the view of consumption. The regressions' adjusted R^2 values are in the interval of 0.69 and 0.94, which means they fit the model good. The estimates for αEGj are all negative, which prove our hypothesis that electricity and natural gas are substitutes in the area of Pacific Northwest. But we can know from the small number that the price sensitives are quite low. What's more, as the real GDP and the weather changes, retail energy consumption ratios are change with the time trend.

Table 2 shows the own-price elasticity estimates for the Pacific Northwest area's retail electricity demands are -0.0284, -0.0009, -0.0197 for the residential, commercial and industrial classes, which means that retail electricity and natural gas demands are inelastic for price.

4. Conclusion

The results conclude that when the price of retail electricity and natural gas changes, consumers will choose the cheaper one to make up for the increased cost of another energy price. Consumers' demand for energy is mainly stable, they won't affect a lot by the change in energy prices.

Table 2. ITSUR regression results of own-price elasticity;

	Residential class: (j = 1)	Commercial class: (j = 2)	Industrial class: (j = 3)	Aggregate
Electri-city	0.0284 (0.0247)	0.0009 (0.0018)	0.0197 (0.0032)	0.0284 (0.0247)
Natural gas	0.1904 (0.0518)	0.0860 (0.0304)	0.0712 (0.0150)	0.1903 (0.0518)

Appendix

Table A1

Data type	Variable (unit)	Mean (M)	Standard deviation (SD)	Coefficient of variation = SD/M	Minimum	Maximum
Residential consumption	Electricity: X_1 (GWh)	1805.39	408.79	0.23	1114.07	2909.86
	Natural gas: Y_1 (MMcf)	5131.73	3314.13	0.65	1182.50	13189.50
Commercial consumption	Electricity: X_2 (GWh)	1446.68	95.05	0.07	1130.81	1675.51
	Natural gas: Y_2 (MMcf)	3446.40	1689.28	0.49	1334.50	7707.50
Industrial consumption	Electricity: X_3 (GWh)	1337.90	226.98	0.17	769.87	1864.86
	Natural gas: Y_3 (MMcf)	5689.87	579.31	0.10	4619.50	7469.50
Residential price	Electricity: E_1 ($/GWh)	82553.85	15364.47	0.19	50800.00	109350.00
	Natural gas: G_1 ($/MMcf)	12481.12	2261.78	0.18	8330.00	18690.00
Commercial price	Electricity: E_2 ($/GWh)	70942.12	11094.67	0.16	46500.00	92500.00
	Natural gas: G_2 ($/MMcf)	9727.54	1580.16	0.16	4505.00	13580.00
Industrial price	Electricity: E_3 ($/GWh)	48697.12	7070.45	0.15	32700.00	75000.00
	Natural gas: G_3 ($/MMcf)	7465.56	1520.10	0.20	4660.00	11595.00
Weather	CDD	76.48	88.14	1.15	5.00	320.00
	HDD	279.62	213.30	0.76	8.00	674.00
Gross domestic product	GDP	5460.83	1268.56	0.23	3254.66	8611.15

Table A2

Data type	Variable	Stationary at 5% level?	Mean (M)	Standard deviation (SD)	Coefficient of variation = SD/M	Minimum	Maximum
Natural log of energy consumption ratio	$\ln(X_1/Y_1)$	Yes	-0.82	0.58	-0.71	-1.65	0.33
	$\ln(X_2/Y_2)$	Yes	-0.74	0.50	-0.68	-1.57	0.09
	$\ln(X_3/Y_3)$	Yes	-1.46	0.25	-0.17	-2.11	-0.94
Natural log of energy price ratio	$\ln(E_1/G_1)$	Yes	1.89	0.24	0.13	1.40	2.43
	$\ln(E_2/G_2)$	Yes	1.99	0.25	0.13	1.49	2.95
	$\ln(E_3/G_3)$	Yes	1.88	0.28	0.15	1.16	2.35
Natural log of real GDP	ln(GDP)	Yes	8.58	0.23	0.03	8.09	9.06
Natural log of weather variables	ln(CDD+1)	Yes	3.60	1.27	0.35	1.79	5.77
	ln(HDD+1)	Yes	5.07	1.31	0.26	2.20	6.51

Table A3

Natural log of energy consumption ratio	Natural log of energy price ratio			Natural log of real GDP	Natural log of weather variables	
	$\ln(E_1/G_1)$	$\ln(E_2/G_2)$	$\ln(E_3/G_3)$	ln(GDP)	ln(CDD+1)	ln(HDD+1)
$\ln(X_1/Y_1)$	-0.397	-0.14	0.173	0.0256	0.949	-0.961
$\ln(X_2/Y2)$	-0.408	-0.164	0.138	-0.0149	0.953	-0.934
$\ln(X_3/Y_3)$	-0.066	0.0825	0.118	0.346	0.695	-0.704

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