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Advertising and the Residential Demand for Electricity*

Recently, considerable effort has been made to reduce the growth rate of electricity consumption in the residential sector through conservational advertising. This paper presents a simple theoretical model of the regulated firm's incentive to reduce the demand for its product through such advertising. An indirect test of this model is provided by estimating a residential electricity-demand equation with utility company advertising included as an independent variable. The empirical results support the theory. Moreover, they indicate that advertising is a statistically significant determinant of the level of electricity demand, but that the advertising elasticity of demand is quite low.

I. Introduction

Following the oil embargo in late 1973, a variety of programs were implemented to reduce the rate of increase of electricity consumption, including advertisements to inform consumers of the cost savings available through conservation measures.[1] Serious doubts have been raised concerning the likely effectiveness of such advertisements in reducing demand. Two basic issues lie at the heart of these doubts. First, since most of these advertising programs were administered by companies that supply electricity, it is difficult to see the incentive of these firms to cooperate in the administration of such programs. Second, no empirical evidence has yet been presented regarding the sensitivity of electricity demand to conservational advertising. Given this lack of evidence, some doubt exists whether demand responds to such efforts at all.

Both of these issues are addressed in this paper. In Section II we present a simple theoretical model that demonstrates the conditions under which the regulated firm will have a profit incen-

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1. Two such programs are the Residential Conservation Service of the U.S. Department of Energy, which performs home energy audits to inform consumers of the relatively more profitable measures available for reducing electricity use, and conservation advertising programs mandated in several states by public service commissions.

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tive to reduce demand. In Sections III and IV we report some empirical results that serve both to test our theory and to measure the advertising elasticity of residential electricity demand. Section V summarizes our results.

II. The Regulated Firm's Incentive to Reduce Demand

In this paper, we view the regulatory process as simultaneously imposing two constraints on the firm's behavior. First, regulators periodically fix the output price (or price schedule) so that a "fair" return on capital can be realized by the firm's investors.[2] In the regulatory short run, then, we assume that output price is parametric to the firm and that the firm can strategically respond to the regulated price by engaging in promotional or conservational advertising before the regulatory agency readjusts the price in response to the firm's advertising program.[3]

Second, the firm must satisfy demand at the regulated price. At the conclusion of a rate hearing then, these two regulatory constraints determine the price and output of the regulated firm at the intersection of the firm's average cost curve and the market demand curve.

The profit of the regulated firm is given by

$$\pi = P_R Q(P_R, \mathbf{X}, A) - C_P[Q(P_R, \mathbf{X}, A)] - C_A(A), \qquad (1)$$

where

P_R = fixed price of output set by regulator;

A = quantity of advertising;

$\mathbf{X}$ = vector of exogenous demand determinants, for example, the price of substitutes and income;

$Q(P_R, \mathbf{X}, A)$ = the quantity of output demanded at P_R, $\mathbf{X}$, and A,

where $(\partial Q/\partial A) > 0$ for promotional advertising and

2. It is well known that if the allowed rate of return on capital exceeds the firm's actual cost of capital, an incentive to employ more than the cost-minimizing quantity of capital in the production process arises (see Averch and Johnson [1962] and the subsequent literature). In this paper, we assume that regulators are successful in setting the allowed rate of return exactly equal to the cost of capital, and in setting output price so that this allowed rate is realized immediately following the rate hearing. Relaxation of this assumption would complicate, but not materially alter, the conclusions reached.

3. This assumption is consistent with Joskow's (1974) description of regulation as an essentially passive process in which prices are adjusted to changes in demand or costs only after considerable delay.

$(\partial Q/\partial A) < 0$ for conservational advertising;

$C_P[Q(P_R, \mathbf{X}, A)]$ = total cost of production, which is a function of the quantity produced; and

$C_A(A)$ = total cost of advertising, with $(dC_A/dA) > 0$ throughout.

Assuming an interior solution, the first-order condition for profit maximization in the regulatory short run implies that

$$\left(P_R - \frac{dC_P}{dQ}\right)\frac{\partial Q}{\partial A} = \frac{dC_A}{dA} \tag{2}$$

where $\partial Q/\partial A$ is positive for promotional advertising and negative for conservational advertising. Since P_R is set equal to average costs, $P_R - (dC_P/dQ) > 0$ when firm output lies in the region of declining average costs, and $P_R - (dC_P/dQ) < 0$ when firm output lies in the region of increasing average costs. Since marginal advertising costs, dC_A/dA, are positive, it follows that advertising will be promotional when average costs are declining and conservational when average costs are rising.

Several authors (e.g., Trebing 1981) have argued that electric utilities moved from the region of declining average costs into the region of increasing average costs sometime around the late 1960s to early 1970s as a result of demand growth. If this is true, then our theory predicts that utility company advertising in the post-1973 era will be of a conservational (demand-reducing) nature. This is the fundamental hypothesis that we will be interested in testing in the remainder of this article.

It is worth pointing out that the results are insensitive to the behavioral assumptions made about the participants in the regulatory process. We have imposed a Cournot-type behavior on both the regulator and the firm. Specifically, the regulator takes as given the firm's cost and demand conditions and sets price accordingly. The firm, on the other hand, takes the regulator's price, which is set equal to average cost, as given and responds strategically to this. One might question the legitimacy of these assumptions in a repeated regulatory process. But suppose instead that regulators are aware of the firm's ability to shift demand. Thus at the rate hearing the output price might be set *below* the firm's average cost with the expectation that the firm will strategically advertise to increase profit. With such an informed regulatory process, the strategically responsive firm can effectively be limited to earn only normal profits even when optimally advertising. The direction of the advertising, however, will still depend on the firm's cost and demand conditions, so the implications of the basic theoretical model still hold.

III. The Empirical Models

Numerous studies have empirically modeled the residential demand for electricity in the United States. A general review of those models reported prior to 1979 is contained in Bohi (1981). Since that time, the structure of the electricity-demand relationship has been estimated by Houthakker (1980) and Beierlein, Dunn, and McConnon (1981). While these studies have clarified some important issues regarding the demand relationship, other questions still remain open. Principal among these is the relationship between advertising expenditures by utilities and the demand for electricity.

In the present analysis, we shall estimate this relationship using data from 34 electric utilities in the northeastern United States for the 1974–79 period. The use of pooled time-series, cross-sectional data that have been disaggregated to the firm level is somewhat unique for electricity-demand estimation. Of the 28 studies reviewed by Bohi (1981), only four utilized firm-level data. Of these, only one study, Gill and Maddala (1978), estimated the demand structure on the basis of pooled observations at the firm level. The advantage of estimating the demand relationship at the firm level is that this disaggregation of data provides additional information that will not affect the expectation of the parameter values, but will reduce their variances.

The particular form of the base-model demand function that we estimate is[4]

$$\ln(Q_{it}) = \beta_0 + \beta_1\ln(P^e_{it}) + \beta_2\ln(P^{ng}_{it}) + \beta_3\ln(P^{fo}_{it}) + \beta_4\ln(M_{it}) + \beta_5\ln(H_{it}) + \beta_6\ln(C_{it}) + \beta_7\ln(A_{it}) + \epsilon_{it}, \tag{3}$$

where

Q_{it} = kilowatt hours per residential customer of electricity sold by company i in year t;

P^e_{it} = the constant dollar average price of residential electricity for company i at time t;

P^{ng}_{it} = the constant dollar average price of residential natural gas in company i's home state in year t;

P^{fo}_{it} = the constant dollar average price of fuel oil in company i's home state at time t;

M_{it} = the constant dollar per capita income in company i's home state at time t;

4. A simple linear functional form was also estimated, but the double-log transformation provided superior results and is therefore reported. In addition, we tested for lagged effects of advertising on demand. Perhaps because of the full year's distance between our time-series observations, no lagged effect was found to exist.

H_{it} = heating degree days in company i's home state at time t;

C_{it} = cooling degree days in company i's home state at time t;

A_{it} = constant dollar advertising expenditures by firm i at time t.

Some attention must be given to the error structure of this equation. We assume a general error structure that permits the possibility of heteroscedastic, autoregressive, and mutually correlated errors (Parks 1967). For convenience we shall refer to this as HAM estimation. That is, the specification of the disturbance term is given by:

$$E(\epsilon_{it}^2) = \sigma_{ii}$$

$$E(\epsilon_{it}\epsilon_{jt}) = \sigma_{ij}$$

$$\epsilon_{it} = \rho_i\epsilon_{i,t-1} + \mu_{it},$$

where

$$\mu_{it} \sim N(0, \phi_{ii})$$

$$E(\epsilon_{i,\ t-1}\mu_{jt}) = 0$$

$$E(\mu_{it}\mu_{jt}) = \phi_{ij}$$

$$E(\mu_{it}\mu_{js}) = 0 \quad (t \neq s).$$[5]

For purposes of comparison, ordinary least squares estimates of the model parameters are also reported.

In addition to this static demand model, a dynamic model was also estimated in which a lagged dependent variable was added to the right-hand side of the regression equation. This dynamic specification takes account of the possibility that adjustment to equilibrium consumption levels is not instantaneous because of lags in adjustments of electricity-using consumer durables.[6]

Finally, to allow the advertising elasticity of demand to fluctuate across observations, we now model the firm's advertising elasticity of demand as a function of the amount of excess capacity (EXCESS) that the firm experienced during the year; that is, we specify that

$$\beta_7 = \alpha_0 + \alpha_1 \ln(\text{EXCESS}_{it}). \tag{4}$$

5. The error-components method of estimation was not used here because it imposes a homoscedatic error structure and a nondampening autocorrelation function (Kmenta 1971). The covariance model for pooling time-series cross-section data was avoided, as it is less general than the model employed and is costly in terms of degrees of freedom.

6. For a complete theoretical derivation of the justification of the dynamic model, see Balestra and Nerlove (1966).

This allows the direction of the regulated firm's optimal advertising policy (promotional versus conservational) to be governed by whether average production costs are falling or rising at the current output level as measured by the excess capacity positions of the firms in our sample. Substituting equation (4) into equation (3), our estimating equation for this model becomes

$$\ln(Q_{it}) = \beta_0 + \beta_1\ln(P^{e}_{it}) + \beta_2\ln(P^{ng}_{it}) + \beta_3\ln(P^{fo}_{it}) + \beta_4\ln(M_{it}) + \beta_5\ln(H_{it}) + \beta_6\ln(C_{it}) + \alpha_0\ln(A_{it}) + \alpha_1\ln(\mathrm{EXCESS}_{it})\ln(A_{it}) + \epsilon_{it}.$$

Following Primeaux (1978) we define excess capacity as the difference between a firm's annualized megawatt capacity and the actual megawatt-hour production by the firm. Based on the theoretical model of the preceding section, our expectation is that the coefficient on EXCESS, α_1, will be positive. That is, as excess capacity increases, the propensity of firms to engage in conservational advertising is diminished. As with the base-model specification, we estimate this expanded model with both ordinary least squares and the more general HAM error structure.

IV. The Data and Estimation Results

The bulk of the data used in this study are taken from *Statistics of Privately Owned Electric Utilities* (U.S. Department of Energy 1974–79). The price, advertising, and income data are deflated by the Consumer Price Index. While the choice of an appropriate price-of-electricity term has been the source of some debate (e.g., see Taylor 1975), we follow Beierlein et al. (1981) in opting for the average, rather than the marginal, price. As Taylor (1975, p. 104) points out, the resulting elasticities must be interpreted as measures of the aggregate price effects. The advertising variable, A_{it}, is defined as the sum of sales advertising expenses, customer service and informational expenses, and general advertising expenses. Our variable excludes expenses incurred on advertising that is explicitly political or public relations in nature. Because the published advertising data are not sufficiently refined, however, we are unable to account explicitly for that component of advertising dedicated to reducing the variance in demand (load management) rather than affecting the level of demand. The data on P^{ng}_{it} are taken from the American Gas Association (1974–79). Fuel oil prices, P^{fo}_{it}, from 1974 to 1977 are taken from the U.S. Department of Energy (1979). Fuel oil price data for 1978 and 1979 were provided verbally from unpublished working documents of the Energy Information Administration. The U.S. Department of Commerce (1974–79) provided the data on heating and cooling degree days. Data on per capita income are from the *Survey of Current Business*.

Because the direction of causality between total advertising expenditures and total firm demand is not altogether clear, we choose to model the dependent variable on a per capita basis. We, therefore, assume that while advertising expenditures affect per capita residential demand, the reverse is not true. If, in fact, this assumption is not accurate and the firm's advertising expenditures do depend on the level of per capita demand, it can be shown that the advertising coefficient in equation (4) will be biased toward zero. Thus, to the extent that we find a significant effect of advertising on consumption utilizing this single-equation approach, our results would be strengthened by adoption of a simultaneous-equation framework.

The results of the base-model demand estimations are presented in table 1. Overall, these results are encouraging. Most of the coefficients are significant and of the expected signs. Also, while the explanatory power of the model is well below that obtained in studies using more aggregate state-level data (e.g., Beierlein et al. 1981), it is within the acceptable range given the relatively disaggregate data employed here.

Of particular interest is the coefficient on advertising expenditures, which is negative and significant at the 5% level. This suggests that advertising expenditures in the 1974–79 period did affect electricity demand. Moreover, the negative coefficient suggests that advertising

TABLE 1 **Residential Electricity Demand in the Northeastern U.S.** (Base-Case Model)†

	Static		Dynamic	
	OLS	HAM	OLS	HAM
Intercept	1.91	8.33	1.76	7.62
	(.95)	(10.67)	(.88)	(11.24)
Price of electricity	−.760	−.295	−.738	−.313
	(−11.23)	(−7.85)	(−10.52)	(−10.39)
Income	.507	−.121	.467	−.011
	(2.03)	(−1.12)	(1.85)	(−.12)
Price of natural gas	−.171	.135	−.158	.102
	(−2.07)	(3.02)	(−1.90)	(2.84)
Price of fuel oil	.074	.109	.072	.056
	(.551)	(2.69)	(.54)	(1.87)
Heating degree days	.327	.040	.360	.207
	(1.07)	(.307)	(1.18)	(2.70)
Cooling degree days	.241	−.096	.241	.064
	(1.22)	(−.932)	(1.22)	(1.87)
Advertising	−.018	−.002	−.020	−.003
	(−1.94)	(−1.53)	(−2.16)	(−3.51)
Lagged output			.068	−.005
			(1.15)	(−.46)
Degree of freedom	158	158	157	157
R^2	.503		.507	

NOTE.—*t*-statistics are in parentheses.

† A standard *F*-test for pooling time-series and cross-sectional data confirms the legitimacy of the pooling approach adopted here.

was of a conservational (demand-reducing) rather than a promotional (demand-increasing) nature during this period, as was hypothesized. This result lends empirical support to the theory of advertising by the regulated firm that we presented earlier. While advertising expenditures have significantly affected demand in the statistical sense, however, the estimations here reveal that the advertising elasticity of demand is quite low. Our results indicate that a 10% increase in conservational advertising expenditures results in less than a two-tenths of 1% decrease in electricity consumption.

In addition to the implications of these results with respect to the advertising-demand relationship, the estimations also provide new evidence regarding other variables that have traditionally been included in electricity-demand studies. The price elasticity of demand for the HAM estimations is around $-.3$, which is somewhat higher than the recent estimates by Beierlein et al. (1981) ($-.09$), and Houthakker (1980) ($-.14$). The income elasticity is positive and significant for the ordinary least squares estimation. For the HAM estimations, however, the suggested income elasticity is negative and insignificant. This result is not inconsistent with Beierlein et al., who found an income elasticity of $-.005$. Also, the HAM estimations provide plausible parameter estimates for the price of substitute fuels. Both natural gas and fuel oil have positive and statistically significant cross-price elasticities.

A final point regarding the base-case estimation worthy of note is the estimated coefficient on the lagged dependent variable. In both the HAM and OLS estimations the coefficient on lagged firm output is small and not statistically significant. This is in contrast to several studies (most recently, Houthakker [1980] and Beierlein [1981]) that have found this term to be positive and quite high. Our finding of a statistically insignificant coefficient on lagged output suggests that the difference between short-run and long-run elasticities is not as large as previously believed. Differences in the estimated coefficients on lagged output, price, income, and substitute fuels in our estimations and those of other studies may, of course, be due to a number of factors, such as more recent data, firm-specific rather than state-level data, and a more complete specification of the demand function that includes advertising.

Now consider the estimation results of table 2. There we report the results of the more general model specification, which allows cross-sectional variation in the advertising elasticity of demand. Again, the results are very encouraging. In particular, for both the HAM and the OLS estimations, we find that the coefficient on the excess-capacity interaction term is positive and statistically significant. This result indicates that firm-level advertising elasticities of demand increase (i.e., become less negative) for firms with higher levels of excess capacity. While none of the firms in our sample exhibit a sufficient level of excess

TABLE 2 **Residential Electricity Demand in the Northeastern U.S.** (Demand Effects of Firm-specific Capacity Constraints)†

	Static		Dynamic	
	OLS	HAM	OLS	HAM
Intercept	4.98	7.17	4.83	6.57
	(2.15)	(5.68)	(2.01)	(6.19)
Price of electricity	−.772	−.298	−.767	−.277
	(−11.58)	(−3.41)	(−10.89)	(−3.59)
Income	.136	.062	.141	.156
	(.48)	(.34)	(.49)	(.98)
Price of natural gas	−.054	.106	−.056	.117
	(−.58)	(1.79)	(−.59)	(1.73)
Price of fuel oil	.096	−.004	.094	−.013
	(.72)	(−.065)	(.71)	(−.21)
Heating degree days	.395	−.065	.399	−.103
	(1.31)	(−.44)	(1.32)	(−.59)
Cooling degree days	.220	−.093	.221	.010
	(1.13)	(−.79)	(1.13)	(−.71)
Advertising	−.089	−.093	−.087	−.099
	(−3.02)	(−5.09)	(2.81)	(−6.17)
Advertising × EXCESS	.003	.004	.003	.004
	(2.53)	(5.19)	(2.25)	(6.054)
Lagged output			.015	−.009
			(.244)	(1.89)
Degree of freedom	157		156	
R^2	.522		.523	

† In addition to the specifications reported here, the possibility that the advertising elasticity of demand is time-dependent was examined and rejected for the 1974–79 period. Furthermore, the possibility that firm size, in addition to excess capacity, affects the advertising elasticity of demand was tested and could not be accepted with an acceptable degree of confidence.

capacity to drive this elasticity to the positive region (i.e., to make the estimated advertising policy promotional in nature), this basic result lends further support to our theoretical model of the optimal type of advertising under regulation.

V. Summary

In this paper, a previously neglected aspect of the electricity demand function has been examined both theoretically and empirically. Specifically, we have analyzed the incentives for, and the effects of, advertising by regulated electric utilities. Our theoretical results indicate that the regulated firm will have a short-run incentive to invest in demand-reducing advertising when the market demand curve intersects the regulated price in the region of increasing average costs. Our empirical results indicate that advertising expenditures by electric utilities have significantly affected demand and have tended to promote the conservation of electricity in the postembargo era.

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