THE DEMAND FOR ELECTRICITY FOR IRRIGATION IN LARAMIE COUNTY, WYOMING

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ABSTRACT

Time series data is used to estimate a demand equation for electricity for irrigation in Laramie County, Wyoming. A Nerlovian Lag is employed to estimate short and long-run elasticities. Results indicate that weather is the most important influence on electricity demand. Electricity demand, both in the short and long run, appears to be inelastic. Hypotheses that electricity demand or elasticity has changed in recent years could not be substantiated. Crop price was found to have an insignificant effect on electricity demand. With higher electricity costs and low crop prices in the future and some producers being forced out of business, the importance of these prices to electricity demand could change substantially.

THE DEMAND FOR ELECTRICITY FOR IRRIGATION IN LARAMIE COUNTY, WYOMING

Introduction

Numerous authors have investigated ~~the~~ irrigation's demand for electricity. Howitt et al. (1980) reviewed some of these studies and the problems involved. Linear programming has often been used to derive demand curves for irrigation water because of "the absence of observations over a wide range of prices." Econometric models have been used to estimate residential, commercial and industrial demand for electricity (E.U.R.D.S., 1977). Little if any work has been done with econometric estimation of irrigation demand for electricity.

Laramie County lies in the southeast corner of Wyoming adjacent to Nebraska and Colorado. The climate in Laramie County is cool and dry with the majority of irrigated crop water needs met by irrigation. Primary irrigated crops are alfalfa, spring grains, dry beans and potatoes. The county is served by the Rural Electric Company which also serves small parts of Colorado and Nebraska. Groundwater irrigation is primarily from the Ogallala aquifer. The climate and soils in the western part of the county are not amenable to crop production.

The purpose of this paper is to estimate a demand function for irrigation electricity using econometric methods.

Data

Data supplied by the Rural Electric Company shows some important historical trends in the area. Table 1 provides data on electricity use, number of irrigation accounts, average horsepower and price charged per kilowatt-hour (kwh). From 1964 to 1969 there was little change in the number of irrigators in the county. From 1969 to 1977 the number of irrigators increased rapidly due to the acceptance of center pivot irrigation. In 1977 a moratorium was imposed on the drilling of new irrigation wells due to declining groundwater levels. The average rated horsepower increased rapidly over 1969 to 1977 due to requirements of the center pivot systems relative to older types. Both the number of accounts and average rated horsepower stabilized considerably after the drilling moratorium was imposed.

Table 1. Data on Electricity Demand for Laramie County, Wyoming.

	Laramie County		Average Rated Horsepower			
Year	Megawatt Hours Use Irrigation	Number of Irrigation Accounts	Total System	Laramie County[a]	Kilowatt Hours per Account per HP	Variable Cost per kwh(¢)
1964[b]	3,404	149		23	993	1.5
65	2,563	148		23	753	1.5
66	3,415	151		23	983	1.5
67	2,684	158		23	739	1.5
68[b]	3,097	153		23	880	1.5
69	4,577	165		25.9	1,071	1.26[c]
70	4,832	177		28.8	948	1.24[c]
71	5,984	184		31.7	1,026	1.22[c]
72	6,229	190	39.0	34.6	948	1.23[c]
73	7,469	213	43.2	39.6	886	1.25[c]
74[b]	11,437	230	47.9	44.5	1,117	1.20[c]
75	14,103	282	54.4	49.5	1,010	1.22[c]
76	18,608	312	60.7	54.5	1,094	1.43[c]
77	19,433	324	61.6	55.4	1,083	1.51[c]
78	20,800	335	61.9	56.6	1,097	1.97
79	17,030	335	63.3	57.8	880	2.675
80	19,295	330	64.7	58.9	993	2.872
81	14,536	331	66.2	60.1	731	3.183
82	13,921	328	67.8	62.0	685	3.41
83[b]	10,864	311	70.7	63.8	548	4.17

[a] Estimated for 1964 through 1981.

[b] Data not used in analysis due to weather data deficiencies.

[c] Due to declining block structure over the period, estimate of average price is based on total electric use. Price may also vary due to rate changes during the season.

The price charged by Rural Electric for electricity actually declined in real terms from 1964 to about 1975. The rapid increase in electricity costs since 1976 have outpaced inflation.

The measure of quantity demanded by the average individual irrigator in this study is kwh used per account per rated horsepower per year. The number of irrigation accounts is less than the number of pumps. Some accounts have more than one pump, and some have none as they are used only to drive the pivot.

As data was not available, it was necessary to make an estimate of rated horsepower for irrigators in Laramie County in order to calculate quantity demanded. Average rated systemwide horsepower for the Rural Electric Company was made available for the years 1972 to 1983 (Table 1). Regression was used to estimate average rated horsepower over time before and after the moratorium on well drilling (Table 2). The estimate of average rated horsepower was adjusted downward by a factor of .91 to allow Laramie County irrigators to have a lower rated horsepower than the system average as indicated by data from 1982 and 1983. An average rated horsepower of 23 was obtained by judgment for the period 1964 to 1968 and is allowed to increase by 2.9 horsepower per year from 1969 to 1972 (Rural Electric Company, personal communication). Weather data were obtained from three weather stations in the county being Albin, Archer and Carpenter. Mean monthly temperature and monthly precipitation data were averaged over the weather stations in the analysis.

Methodology

Total electricity use for irrigation in Laramie County depends partially on number of irrigation pumps and the rated horsepower of the motors. For the individual irrigator the cost of irrigation, the expected price of the product and weather conditions should influence his use of electricity for irrigation.

Table 2. Equations to Estimate Average Rated Horsepower and Number of Irrigation Accounts in Laramie County, Wyoming.[a]

		R^2	F	DW
(1)	HPE = -355.00 + 5.46 YR (22.51) (.30)	.99	322	1.42
(2)	HPL = -38.646 + 1.294 YR (8.17) (.10)	.98	159	1.55
(3)	AC = 345.113 - .017 HPC (1.193) (.0015)	.98	130	2.45

Variable Definitions

HPE = average rated horsepower systemwide for 1972 to 1976

YR = year, expressed as last two digits, i.e., 72 to 82

HPL = average rated horsepower systemwide for 1977 to 1982

AC = number of irrigation accounts in Laramie County, Wyoming, 1978 to 1982

HPC = demand charge per horsepower in dollars times estimated average horsepower for Laramie County times 100, all divided by the GNP implicit price deflator (1983 = 100)

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[a] Standard deviation given under each estimated parameter in parentheses.

Increased electricity price per kwh is hypothesized to influence electricity use negatively. A partial adjustment model is used to derive short run and long run elasticities of demand. The lagged dependent variable is used as an independent variable. The long run demand coefficient is $B^* = B_1|(1-B_2)$ where B_1 is the estimated parameter on price per kwh and B_2 is the estimated parameter on the lagged dependent variable (Nerlove and Addison, 1958).

Table 2 provides an estimate of the number of irrigation accounts in Laramie County. Irrigators must also pay a seasonal "demand charge" based on the rated horsepower of their pump. As indicated by the significant coefficient on HPC, this charge may be a deterrent to contracting for seasonal irrigation service.

It can be argued on economic grounds that the "demand charge" should not be included as an independent variable affecting electricity use. This is because, once paid, the "demand charge" is a fixed cost invariant with respect to seasonal electricity use. On the other hand, irrigators may feel that, with higher demand charges, savings must be made by lower electricity use to stay within some allowable irrigation expense. The importance of the demand charge to electricity use is tested for by inclusion of this variable.

Weather is considered to be an important determinant of irrigation levels and consequent electricity use per irrigator per rated horsepower. Precipitation decreases the need for irrigation. Increased temperature should be associated with increased electricity demand through increased evapotranspiration.

Increased crop prices are hypothesized to impact electricity use positively. Producers may respond to high crop prices by trying to increase yields through increased irrigation.

Several hypotheses related to the structure of demand and structural change over time will be tested. There has been some changeover to low-pressure center pivot systems in recent years, and innovations in irrigation scheduling and other technologies should allow irrigators to use less electricity. A dummy variable for the period since the moratorium on well drilling (1978-1982) is used to test the hypothesis that, all else equal, irrigators were using less electricity per account per horsepower from 1978 to 1982.

By multiplying the dummy variable times electricity price, change in response to electricity price can be tested for. With higher electricity prices and increasing production costs from 1978 to 1982, irrigators might have become more responsive to price changes.

During the period 1969 to 1977, irrigators faced a declining block structure in the charge per kwh. Most center pivot irrigators would have easily passed the first block and, at the margin, were paying based on the lower rate associated with the second block. The question arises as to whether the season average price or the marginal second block price is the most important influence on quantity demanded. Price variables are constructed to reflect both the season average and second block price to see which most significantly influences demand.

Results

Weather variables were entered into ordinary least squares regression equation by order of seasonal occurrence in order to determine the amount of variability in electricity use that can be accounted for by successive weather variables.

Table 3 provides four regression equations using weather data to the end of April, June, August and September, respectively. The equations account for 50, 75, 93 and 98 percent of annual variability in electric use per account per horsepower. This demonstrates the difficulty in predicting electricity use early in the irrigation season when weather cannot be predicted.

Equation (7) is the final demand equation. Crop prices were found to have an insignificant effect on electricity use. Once irrigation is started, irrigators apparently water their crops according to water needs without much consideration of crop price.

Electricity demand is found to be insignificantly related to April temperature after the inclusion of September temperature. May to September mean temperatures are significantly and positively related to electricity use as expected. Precipitation from March to April and July to August are significantly and negatively related to electricity use. The lagged dependent

Table 3. Estimation of Electricity Demand Equations Showing Contribution of Weather Variables As Irrigation Season Progresses.[a/]

		R^2	F	DW
(4)	KWACHP = 1298.36 - 141.44 KWC - .189 HP - 20.13 MAP + 5.08 AT	.50	2.75	
	(447.15) (47.13) (.136) (28.51) (9.54)			
(5)	KWACHP = 118.64 - 86.59 KWC - .222 HP - 27.77 MAP + 11.65 AT	.75	4.61	
	(831.06) (41.16) (.106) (23.35) (9.40)			
	- 34.91 MJP + 16.33 MJT			
	(18.94) (15.60)			
(6)	KWACHP = 2674.25 - 76.68 KWC - .093 HP - 20.56 MAP + 15.75 AT	.93	8.50	
	(2761.30) (30.32) (.083) (16.98) (6.80)			
	- 36.12 MJP + 16.29 MJT + 1056.9 JAP - 38.95 JAT - 75649.7 (JAP/JAT)			
	(16.91) (10.82) (946.6) (40.47) (64804.3)			
(7)	KWACHP = 6032.87 - 75.39 KWC - .14 HP - 30.47 MAP	.98	30.54	2.04
	(1487.51) (17.96) (.04) (8.60)			
	- 11.79 MJP + 24.93 MJT + 2329.9 JAP - 102.6 JAT - 163188 (JAP/JAT)			
	(7.28) (4.88) (545) (22.36) (37327)			
	+ 17.16 ST + .124 KWACHP_{y-1}			
	(3.23) (.125)			
	(4.45)			

[a/] N = 16, R^2 = equation R^2, F = equation F-statistic, DW = Durbin-Watson Statistic. Estimated standard errors given below each estimated parameter in parentheses.

Table 3. (continued)

Variable Definitions

KWACHP = seasonal kilowatt-hours used per account per rated horsepower in Laramie County

KWC = average seasonal price charged per kilowatt-hour, divided by the GNP implicit price deflator (1983 = 100)

HP = average demand charge per irrigator; equals charge per horsepower times average rated horsepower, divided by the GNP implicit price deflator

MAP = $[(MRP_{al} + MRP_{ar} + MRP_{ca})/3] + [(APP_{al} + APP_{ar} + APP_{ca})/3]$
AT = $(APT_{al} + APT_{ar} + APT_{ca})/3$
MJP = $[(MYP_{al} + MYP_{ar} + MYP_{ca})/3] + [(JNP_{al} + JNP_{ar} + JNP_{ca})/3]$
MJT = $[(MYT_{al} + MYT_{ar} + MYT_{ca})/3 + (JNT_{al} + JNT_{ar} + JNT_{ca})/3]/2$
JAP = $[(JLP_{al} + JLP_{ar} + JLP_{ca})/3] + [(AGP_{al} + AGP_{ar} + AGP_{ca})/3]$
JAT = $[(JLT_{al} + JLT_{ar} + JLT_{ca})/3 + (AGT_{al} + AGT_{ar} + AGT_{ca})/3]/2$
ST = $(SPT_{al} + SPT_{ar} + SPT_{ca})/3$
MRP = March precipitation, inches
al = Albin weather station, WY
ar = Archer weather station, WY
ca = Carpenter weather station, WY
APP = April precipitation, inches
APT = April mean temperature, °F
MYP = May precipitation, inches
JNP = June precipitation, inches
MYT = May mean temperature, °F
JNT = June mean temperature, °F
JLP = July precipitation, inches
AGP = August precipitation, inches
JLT = July mean temperature, °F
AGT = August mean temperature, °F
SPT = September mean temperature, °F

variable is insignificant but is included in equation 7 to allow for estimation of long run demand elasticity.

Table 4 provides estimates of response of electricity use to the weather variables. Due to the interaction term on July and August precipitation and temperature, response is evaluated at the mean of each; 3.69 inches and 68.94 degrees, respectively. The weather data indicates that the standard deviation of monthly mean temperature is two to five degrees with the lower deviation in the summer months. The standard deviation of monthly precipitation is around one to two inches. Combined with Table 4, this indicates that frequent non-trivial annual variations in electricity demand occur due to variations in weather.

Table 4. Estimated Impact of Precipitation and Temperature on Electricity Use and Expense.

Weather Variable	Coefficient[a] on Variable	As Percent[b] of Mean	1983 kwh[c] Change in Demand, 1983	1983 Change in Variable Returns/Account	1983[d] Change in Utility Revenues
MAP	-30.47	-3.3	-595,254	$79.81	$-24,822
MJP	-11.79	-1.3	-233,935	31.37	-9,755
JAP	2329.9	-4.0[e]	-732,162	98.17	-30,531
MJT	24.93	2.7	494,656	-66.33	20,627
JAT	-102.6	2.4[e]	438,164	-58.75	18,271
ST	17.16	1.8	340,485	-45.65	14,198
JAP/JAT	-163188				

[a] From equation 7, the amount kwh per account per hp changes with a one unit change in the dependent variable.

[b] The mean is 932.52 kwh per account per hp.

[c] There were 311 accounts with an average rated horsepower of 63.8 in 1983. Electricity cost was 4.17¢ per kwh in 1983. Expressed as change per inch precipitation or degree F.

[d] From Laramie County only.

[e] All estimated responses from here to the right account for the interaction.

The coefficients on price per kwh, the demand charge and the lagged dependent variable can be used to estimate price elasticities of electricity demand. Average annual kwh use per account per horsepower over the entire period was 932.52. Average adjusted kilowatt hour price and demand charge were 3.14 and 489.34, respectively. The short run elasticity of demand with respect to kilowatt-hour price is $-(3.14/932.52) \times 75.39 = -.25$. Short run elasticity with respect to the demand charge is $-(439.34/932.52) \times .14 = -.07$. These inelastic demands indicate that irrigators are fairly unresponsive to price changes. A one percent increase in kilowatt-hour price will bring only a .25 percent reduction in electricity use. As expected, electricity demand is even less responsive to the "demand charge". After being paid, it is a fixed cost for the remainder of the season.

The partial adjustment lag uses the coefficient of adjustment to determine long run elasticity. The coefficient of adjustment equals one less the estimated coefficient on the lagged endogenous variable and is $1 - .124 = .876$. The long run price elasticities on kilowatt-hour price and the demand charge are $-(3.14/932.52) \times (75.39/.876) = -.29$ and $-(439.34/932.52) \times (.14/.876) = -.075$, respectively.

These long run elasticities are quite close to the short run elasticities (-.25 and -.07). They indicate that most irrigator response to price change occurs within a year of the price change.

The total quantity of electricity demanded from Laramie County irrigators is

$$Q_d = (KWH/AC/HP) * AC * HP \qquad (8)$$

where Q_d is quantity demanded, KWH is kilowatt hours, AC is number of accounts and HP is horsepower. From equation (2) and (3), HP has been rising over time. This increases horsepower cost such that the number of accounts falls. An increase in the demand charge thus decreases demand through KWH/AC/HP and AC.

The inelastic response to variable electricity price indicates that utilities might be able to control revenues by changing variable price.

Irrigators may be unresponsive to variable electricity price because, within current price ranges, the value of the marginal product of yield produced may exceed the marginal cost of producing that incremental yield up to maximum yield (Mann et al., 1984).

Equation (7) predicts electricity use quite well over the period used for estimation. The size of the error terms ranges from 0 to 5 percent and exceeds 2% of predicted levels in only 3 out of 16 years. Unfortunately, this is of little help to electric utilities who cannot know weather in advance. Estimates of prediction error from equations (4) to (6) in Table 3 would be substantially larger.

Hypotheses related to structural change, the demand charge and declining block pricing are tested through equations presented in Table 5.

Equation (9) excludes the demand charge variable HPC. An F-statistic less than half that for equation (7) lends support to the hypothesis that the demand charge does influence quantity of electricity consumed. That is consistent with the notion that irrigators may try to compensate for a higher demand charge, a fixed cost, by reducing variable electricity use.

Equation (10) allows for a dummy slope shifter on electricity price for the period 1978 to 1982. The insignificance of the variable KWHDUM and a lower equation F-statistic, relative to equation (7), indicates that irrigators have not significantly altered their response to electricity price in current years. If anything, the positive sign on KWHDUM indicates that irrigators were less responsive to electricity price from 1978 to 1982 than in previous years.

Table 5. Estimation of Electricity Demand Equations with Alternative Functions to Test for Some Hypotheses Related to Electricity Demand Structure.

		R^2	F
(9)	$KWACHP = \underset{(2345.2)}{5830.9} - \underset{(27.73)}{63.69}KWC - \underset{(13.39)}{26.00}MAP - \underset{(11.17)}{17.09}MJP + \underset{(7.69)}{24.44}MJT + \underset{(857.1)}{2165.3}JAP - \underset{(35.22)}{98.66}JAT - \underset{(58663)}{152575}(JAP/JAT) + \underset{(4.97)}{14.97}ST + \underset{(.20)}{.16}KWACHP_{y-1}$	.95	13.18
(10)	$KWACHP = \underset{(1574.85)}{6113.42} - \underset{(25.67)}{87.44}KWC + \underset{(17.26)}{12.02}KWHDUM - \underset{(.121)}{.217}HP - \underset{(9.24)}{29.31}MAP - \underset{(8.75)}{8.87}MJP + \underset{(5.5)}{26.3}MJT + \underset{(582.1)}{2387.7}JAP - \underset{(23.61)}{103.02}JAT - \underset{(39799)}{167044}(JAP/JAT) + \underset{(3.59)}{16.38}ST + \underset{(.15)}{.08}KWACHP_{y-1}$	.99	24.95
(11)	$KWACHP = \underset{(1451.5)}{6023.94} - \underset{(22.41)}{91.02}KWC - \underset{(.10)}{.24}HP + \underset{(48.34)}{54.07}DUM - \underset{(8.74)}{27.77}MAP - \underset{(7.98)}{7.73}MJP + \underset{(4.9)}{26.6}MJT + \underset{(533.8)}{2372.4}JAP - \underset{(21.85)}{101.22}JAT - \underset{(36505)}{165934}(JAP/JAT) + \underset{(3.31)}{16.02}ST + \underset{(.14)}{.05}KWACHP_{y-1)}$	.99	29.27
(12)	$KWACHP = \underset{(1506)}{6727.8} - \underset{(13.7)}{57.02}KWCA - \underset{(.04)}{.106}HP - \underset{(8.70)}{31.92}MAP - \underset{(7.27)}{12.28}MJP + \underset{(4.93)}{26.42}MJT + \underset{(550.1)}{2614.6}JAP - \underset{(22.58)}{116.6}JAT - \underset{(37627)}{182770}(JAP/JAT) + \underset{(3.26)}{17.47}ST + \underset{(.12)}{.21}KWACHP_{y-1}$	.98	30.13

Table 5. (continued)

Variable Definitions
(See Table 3)

KWHDUM = DUM x KWC

DUM = 1 if year is 1978 to 1982, = 0 if year is 1964 to 1977

KWCA = average seasonal price charged per kilowatt-hour for the lowest priced block if declining block was used, divided by the GNP implicit price deflator (1983 = 100)

To test if electricity use was more or less in the period 1978 to 1982 a dummy variable was employed in equation (11). Although the variable is not significant ($\alpha = .05$), the positive sign on DUM indicates that electricity use per account per horsepower may have increased in the period 1978 to 1982, even with conversion to low-pressure center pivots.

In equation (12) the electricity price variable is the second block price for the period 1969 to 1977. The slightly larger T-statistic on the price variable in equation (7) indicates that average price paid over the two blocks is a better indicator of demand than price paid for the second block, although the difference is certainly not significant.

Summary

The results indicate that weather variables can explain a large proportion of variation in demand for electricity for irrigation. Electricity use appears to have been inelastic with respect to electricity prices, and the effect of crop prices on the amount of electricity used is insignificant. With useful long-term weather predictions, utilities might be better able to predict electricity use. This has implications for pricing and production policies of the utility.

Hypotheses that irrigators were more efficient and price responsive in the period 1978 to 1982 than in previous years cannot be substantiated. Calculated long run demand elasticities are very close to short run elasticities indicating that most response of irrigators to price changes will occur within a year. Both long and short run elasticities suggest inelastic response to electricity prices.

The insignificance of crop price and the inelastic response to electricity price may not continue in the future. With increasing electricity price, decreased groundwater levels and low crop prices, some producers may be forced out of business. The entire structure of response to prices could change. In the past, increasing numbers of irrigation accounts was due largely to strong crop prices, low energy prices and some subsidy for irrigation development. In the future, decreasing numbers of accounts may follow from economic depletion of groundwater levels.

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