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IRRIGATION AND THE DEMAND FOR ELECTRICITY*

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IRRIGATION AND THE DEMAND FOR ELECTRICITY

ABSTRACT

In order to anticipate the need for generating capacity, utility planners must estimate the future growth in electricity demand. The need for demand forecasts is no less important for the nation's Rural Electric Cooperatives (RECs) than it is for the investor-owned utilities. The RECs serve an historically agrarian region; therefore, the irrigation sector accounts for a significant portion of some of the Cooperative's total demand. This paper develops a model of the RECs' demand for electricity used in irrigation.

The model is a simultaneous-equations system which focuses on both the short-run utilization of electricity in irrigation and the long-run determination of the number of irrigators using electricity. Irrigation demand is described by a set of equations in which the quantity of electricity demanded, the average electricity price and the number of irrigation customers are endogenous. The structural equations are estimated using pooled state-level data for the period 1962-1977. In light of the model's results, the impacts of changes in relative energy prices on irrigation are examined.

IRRIGATION AND THE DEMAND FOR ELECTRICITY

INTRODUCTION

The study of the irrigation demand for electricity provides a perspective on both the need for electricity and the impact of changes in relative energy prices on agriculture. Although irrigation accounts for only one percent of total electricity consumption in the United States,[1] demand for electricity for irrigation can account for a large portion of total sales for rural-based electric utilities. For example, in 1974, irrigation accounted for sixty percent of all electricity used in agricultural operations. Electricity is used to pump water to approximately one-third of all irrigated acres.[2] Thus, continual increases in electricity prices have a potentially dramatic impact on irrigated agriculture.

The nation's Rural Electric Cooperatives (RECs) are the logical focus for an examination of irrigation and electricity because their service areas are predominately agricultural. Farmers were the major impetus for the creation of the RECs. The first cooperatives were organized in the mid 1930's under the direction of the Rural Electrification Administration (REA).[3] REA was established to provide loans at low interest rates to extend electric service into the hinterlands. When REA was created, only eleven percent of farms had electricity. Over the subsequent forty-five years, this figure has grown to ninety-nine percent, the result of combined efforts of REA-financed systems and commercial utilities [USDA, 1978, p. 498].

Today, REA borrowers serve farm and nonfarm customers, commercial enterprises and industrial firms. All together, they serve 8.8 million customers along nearly 2 million miles of distribution lines. The over 900 financed systems earned combined revenues of $4.8 billion on assets of $10 billion in 1978. Approximately one-third of the Cooperatives' power is self-generated; the remainder is purchased from other sources [USDA/REA, 1978].[4]

Irrigation accounts for over twenty percent of the total kilowatt hours sold by REA borrowers in states such as Colorado, Idaho and Washington. Some service areas are heavily dependent upon sales for irrigation; for example, 82% of the kilowatt hour sales of the Raft River Rural Electric Cooperative in Malta, Idaho went to pump water for irrigation systems in 1978.

This investigation of the cooperatives' irrigation demand follows other studies which have dealt with energy and irrigation. The next section reviews some of this literature. The third section presents a simultaneous-equations model for irrigation demand for electricity. The empirical estimation using pooled state-level data for the period 1962-1977 is then described. The final section reflects upon the potential impact of changes in relative energy prices on irrigation demand in light of the model's results.

IRRIGATION AND ENERGY

Water is an input to crop production. The farmer's cheapest source of water is precipitation, but the weather only coincidentally cooperates to produce the optimal amount of rainfall. In order to exercise some control over the amount of water applied to his field, the farmer can turn to irrigation.

Irrigation is defined as the artificial application of water to enhance plant growth. To be the functional equivalent of precipitation, water used for irrigation must be delivered to the root system of the growing plants. The irrigating farmer calculates the correct amount of water according to the crops he grows, the characteristics of the soil, and the climate.[5] Costs of bringing the water to growing crops varies greatly from farm to farm. Water can be drawn from streams, pumped from groundwater sources of varying depth, stored and diverted using dams and distribution channels, and applied in furrows or by sprinkler systems. For approximately two-thirds of all irrigated acres in 1974, energy was combined with labor and capital to deliver the water across the fields. The amount of power needed to pump the water varied with the distance the water traveled and the volume of the pipes. For the balance of irrigated acres, pumping of water was not required because the systems relied on gravity; irrigation water was combined with the capital of the irrigation system to produce a rainfall-equivalent.

Previous studies of energy and irrigation have tended to be descriptive or based upon linear programming models. Sloggett [1979] has developed estimates of energy use by fuel type by state for 1974 and 1977. This study provides an excellent reference for comparing fuel-use patterns among states. King et al. [1978] have formulated a linear programming model of optimal water and energy use for the Pacific Northwest. The constraints are based upon estimates of factor costs and the current irrigation capital stock. Mapp and Dobbins [1976] have developed a linear model of irrigation in the Oklahoma Panhandle. Natural gas accounts for 91% of the energy used for pumping water in this region, and the model predicts that rising natural gas prices will result in decreasing the acres irrigated. However, there is no provision for fuel switching in the model and, thus, it may overlook the potential of fuel substitution between natural gas and other substitutes such as electricity and gasoline. In a more recent study, Katzman and Matlin [1978] discuss the market penetration of solar-powered irrigation systems, and estimate that solar will be cost competitive by 1990. Of course, if solar power penetrates the irrigation sector, the irrigation demand for conventional fuels such as electricity would decrease.

The model presented in the next section differs from previous studies of energy and irrigation because it estimates both short-run and long-run own-price and cross-price elasticities using a simultaneous-equations, econometric model of irrigation demand for electricity.

MODEL SPECIFICATION

Irrigation demand for electricity is a derived demand. It is derived from the demand for water for the purpose of crop production. Electricity is used as a power source to drive the water pump. In general, farmers who use energy for irrigation first choose among alternative pumping systems powered by either electricity, natural gas, or some other fuel. Once the specific pumping equipment is in place, farmers can, in the short run, adjust only the rate of utilization of this equipment. Thus, a model must reflect both the short-run and the long-run phenomona of electricity demand.

Electricity Usage Equation

To develop the short-run usage equation, consider first the following production function:

$$Q = f_Q(K, L, R_I, R_D, T, W_N, W_A) \tag{1}$$

where Q = crop production

K = capital

L = labor

R_I = irrigated acres

R_D = dryland acres

T = temperature

$\bar{W}_N$ = natural precipitation

W_A = artificial precipitation

In this production function, artificial precipitation can be described by another set of input factors, including electricity. Thus, assuming homothetically weak separability, equation (1) can be rewritten as:

$$Q = f_Q(K, L, R_I, R_D, T, W_N, g(E, X)) \tag{2}$$

where E = electricity input

X = other inputs.

Applying the duality theorem, the corresponding cost function is:

$$C = f_C(P_K, P_L, P_R, g(P_E, P_X)) \tag{3}$$

where the P's are input prices. Minimizing (3) subject to (2) yields the following derived demand function for electricity:

$$E = f_E(P_E, P_X, Q, R_I, T, W_N). \tag{4}$$

The inclusion of R_I is due to the fact that if cropland is not irrigated, the demand for electricity vanishes. Similarly, if the temperature is moderate and natural precipitation is optimal, there will be no need for irrigation and no derived electricity demand. Therefore, T and W_N should also be included.

Equation (4) provides the basis for formulating the short-run electricity usage equation. However, the specific econometric formulation depends upon data availability. Therefore, alternative proxi measures are used for some variables. The log-linear specification may be written as follows:

$$\begin{aligned} \ln(E/N)_t = \alpha_0 + \alpha_1 \ln PE_t + \alpha_2 \ln ARID_t + \alpha_3 \ln PK_t \\ + \alpha_4 \ln PL_t + \alpha_5 \ln(VC/A)_t + \alpha_6 \ln(R_I/F)_t \\ + \alpha_7 D_t + \varepsilon_t \end{aligned} \tag{5}$$

Where $t \equiv$ time period (year)

$E =$ quantity of irrigation electricity sales

$N =$ number of irrigation customers

$PE =$ average price of electricity

$ARID =$ aridity index

$PK =$ cost of capital

$PL =$ labor cost

$VC/A =$ value of crops per acre

$R_I/F =$ irrigated acres per farm

$D_t =$ set of state dummy variables, varies by region

$\varepsilon_t =$ disturbance term

The variables PE, PK, PL and VC/A are deflated by the cost-of-living index to reflect real values.

The aridity index is an attempt to capture the effects of weather on variations in crop yields. It is constructed as the ratio of actual evapotranspiration, which measures the water actually evaporated and transpired from the leaves and stems of a plant, and potential evapotranstransporation [Strand, 1978]. The index combines information about temperature, rainfall and wind velocity. The greater the ratio, the less the need for irrigation. Therefore, one would expect α_2 to be negative.

The cost of capital and the wage rate are used in the model to reflect the fact that electricity is combined with equipment and labor for irrigation. There are several types of irrigation systems, ranging from Center Pivot and Big Gun sprinkler methods to gravity-flow systems. The energy efficiency of each method varies, with relatively more energy required per gallon of water supplied by the sprinkler systems. Recognizing the difficulty in estimating irrigation equipment costs specifically, the model is formulated using the cost of capital in agriculture. Assuming competitive markets, farmers will invest in equipment for all purposes so as to equate the marginal return across uses. Since capital is used with the electricity, one would expect α_3 to be negative.

Since PK is not directly measurable, a proxy is used. Data is not available to calculate the rate of return on the current value of assets in agriculture by state. The simplifying assumption is made that production expenses are directly proportional to the current value of assets. Therefore, PK can be reflected by the ratio of net farm income to farm production expenses.

Several economists have made studies of labor requirements for various irrigation systems. Depending upon the technology, it is estimated that irrigation can require anywhere from 0.01 to 0.35 man hours per acre-inch of water applied.[6] Therefore, once the irrigation system is selected, electricity and labor are complements. However, the quantity of both electricity and labor depends upon the choice of the application system. Gravity systems are relatively labor intensive, but use little or no energy. At the other extreme are the center pivot sprinklers which are energy intensive but use very little labor. Therefore, electricity and labor can also be substitutes.[7] The value of the coefficient α_4 is thus indeterminant. In this formulation, the price of labor is the hourly wage paid to field and livestock workers.

The derived factor demand equation includes a variable to reflect quantity of output. Because of the difficulty in adding "apples and oranges," however, the value of crops produced is used as a proxy. Since the dependent variable is not total electricity demand but electricity use per customer, the value of crops produced in the state is deflated by the number of acres in farms. It is assumed that increases in this variable reflect increasing yield per acre, which can be brought about through increased use of factor inputs, such as electricity. Therefore, α_5 should be positive.

The more acres irrigated on the farm, the more electricity an irrigation customer will demand. The coefficient α_6 is expected to be greater than zero.

One way to capture the variation in energy requirements for irrigation systems is through regionalization. For example, states in the Southwest such as Oklahoma, Texas, New Mexico and Arizona depend upon deep groundwater sources while states such as Colorado, Wyoming and Montana depend to a much greater extent on shallow ground water and surface water [Dvoskin and Heady, 1976, p. 154]. Therefore, the model coefficients should be estimated by region. In order to reflect state-level differences not reflected by the other variables, state dummy variables are included in the equation.

The price of water is not included in the model. Since most farmers are either not charged a water fee, or pay water charges well below its marginal value, this omission should not affect the results.[8]

Price Equation

In equation (5), average electricity price, instead of the theoretically more plausible measure of marginal price, is used. The problem of using average price under the declining block rate schedule is by now well recognized [Taylor, 1975]. In order to obtain a consistent estimate of the price coefficient, the average price is considered to be endogenous. Employing the approach used by Chern et al., [1978], the price function is linear with a quadratic term:

$$PE\text{-}C = \beta_0 + \beta_1(E/N)_t + \beta_2(E/N)_t^2 + \beta_3 N_t + \beta_4 D_t + \mu_t \qquad (6)$$

where C is the average total cost of generation, transmission and distribution[9] and μ_t is the disturbance term. As shown in Chern et al., [1978], this particular constrained formulation of the price function ensures that the sectoral prices are bounded by the utility system's average cost and, thus, it produces more plausible price forecasts than the unconstrained logarithmic specification used by Halvorsen [1976].

Customer Equation

In the short run, farmers are constrained by the type of irrigation equipment they have. Thus, the number of irrigation customers demanding electricity, N, in equation (5) is fixed in the short run. However, in the long run, farmers can replace their pumping equipment and switch from electricity to other fuels and vice versa. New electricity customers can be added as the number of irrigation farmers increases. Thus, our problem in modeling electricity demand for the long run is to determine the number of irrigation customers, N.[10]

It is appropriate to assume that the relative prices of fuels are the major determinants of the farmers' power selection. The following fuel choice equation is specified in terms of the number of irrigation customers:

$$\ln N_t = \gamma_o + \gamma_1 \ln N_{t-1} + \gamma_2 \ln PE_t + \gamma_3 \ln PG_t + \gamma_4 \ln PD_t + \gamma_5 \ln PO_t + \gamma_6 \ln(R_I)_t + \gamma_7 D_t + \nu_t \quad (7)$$

where PG = price of natural gas

PD = price of diesel fuel

PO = price of gasoline

ν_t = disturbance term

The price variables are deflated by the cost of living index. The lag term is included to capture the long-run dynamic adjustment process. The number of irrigated acres, R_I, is used as an indication of the scale of irrigation operations in the state. Even though relative fuel prices remain constant, the number of irrigation farmers using electricity may increase as more acres are irrigated. This reasoning leads to the expectation that γ_6 will be positive.

Calculation of Elasticities

Equations (5), (6), and (7) are the structural equations of the model. By combining (5) and (7), it is a simple exercise to show that in the short-run, the own-price elasticity will be:

$$\frac{\partial \ln E}{\partial \ln PE} = \alpha_1 + \gamma_2 \quad (8)$$

In the long-run, the number of customers will reach a steady-state and the price elasticity will become:

$$\frac{\partial \ln E}{\partial \ln PE} = \alpha_1 + \gamma_2/(1-\gamma_1) \tag{9}$$

The short-run cross-price elasticities are simply the coefficients of the fuel-price variables. In the long run, the cross-price elasticities can be calculated by

$\gamma_i/(1-\gamma_1)$ for $i = 3,4,5$.

The next section describes the estimation of the model and highlights the regional differences.

MODEL ESTIMATION

The parameters of the model presented in the previous section are estimated simultaneously by region. The thirty-three states in which the Cooperatives consistently sell electricity for irrigation are divided into five regions (see Table 1). Texas is considered separately because of the large number of irrigation customers in the state (see Table 2). Texas has the smallest growth in average electricity usage per customer, and the growth rate in the number of customers is almost twice that for the rest of the Southwest.

The model is estimated using annual, state-level data from 1962- to 1977. The three equations are estimated simultaneously using three-stage least squares. The four multi-state retions are estimated by pooling the cross-sectional, time-series data. The basic information on electricity sales, revenue and number of customers of the RECs is published annually by REA. The Appendix lists the sources of the other variables used in the model.

Table 1. Irrigation Regions

Region	Member States
Southeast	Alabama, Florida, Georgia, Mississippi, North Carolina, South Carolina, Virginia
Midwest	Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, South Dakota, Wisconsin
Northwest	California, Colorado, Idaho, Montana, Nevada, Oregon, Utah, Washington, Wyoming
Southwest	Arizona, Arkansas, Lousiana, New Mexico, Oklahoma
Texas	Texas

Table 2. Operating Statistics by Region

Variable and Year	Southeast	Midwest	Northwest	Southwest	Texas
Customers					
1962	1570	8497	11896	7144	15404
1977	4663	29923	30999	12569	39846
Annual % growth (1962-77)	7.52	8.76	6.59	3.84	6.54
Average usage (10^3 kwh/cust.)					
1962	13.16	6.03	24.33	30.03	21.45
1977	15.59	25.05	75.06	44.64	19.14
Annual % growth (1962-77)	1.14	9.96	7.80	2.68	-0.76
Average price (¢/kwh)					
1962	2.32	3.16	1.40	1.73	1.69
1977	4.96	4.32	1.76	2.93	3.66
Annual % growth (1962-77)	5.20	2.11	1.54	3.57	5.29

Table 3 and 5 present the estimated coefficients of the three equations describing the irrigation sector. The details of the coefficients of the state dummy variables do not add to the interpretation of the results and are not included here for simplicity in presentation.

There are substantial regional differences among the estimated parameters of the model. These results highlight the differences in the impact of the variables on the farmers' decision to irrigate depending upon the section of the country in which they operate.

The results show that electricity price is the most important factor influencing irrigation demand for electricity. The price coefficients are significant for all regions except in Texas, where the limited number of observations may have contributed to the low t statistic.

The aridity index is a significant determinant of demand in the Midwest, Southwest and Northwest (see Table 3). As expected, the coefficient is less than zero. The West suffers from periods of extreme heat with little rainfall, and irrigation is used to compensate for these conditions. The Southeast, on the other hand, shows no significant impact of weather, as measured by the aridity index, on the demand for electricity for irrigation. Some crops grown in this region, such as rice, require a certain level of irrigation irrespective of temperature. The coefficient of the aridity index is negative in Texas, but not significant at the .05 level.

As expected, the coefficient of the proxy for the cost of capital in agriculture is negative for all regions. The Southwest and Northwest have relatively lower elasticities of electricity demand to capital cost. This result reflects the fact that farmers in these regions have little choice but to invest in irrigation equipment if they want to grow crops. The farmer in the Southeast, on the other hand, has a relatively wider

Table 3: Irrigation Demand per Customer

Three Stages Least Squares Estimates by Region, 1962-1977[a]

Normalized Variable: ln E/N

Variable	Southeast	Midwest	Northwest	Southwest	Texas
Interept	8.633	6.472	6.729	4.915	2.992
	(10.206)	(5.580)	(20.903)	(8.179)	(1.265)
ln PE	-1.973	-1.195	-1.141	-0.195	-.359
	(-7.150)	(-4.346)	(-16.342)	(-1.900)	(.594)
ln ARID	.020	-1.741	-.691	-1.335	-1.642
	(.019)	(-1.977)	(-3.591)	(-2.959)	(-1.666)
ln PK	-.455	-.293	-.136	-0.119	-.223
	(-3.029)	(-2.737)	(-4.618)	(-1.815)	(-1.499)
ln PL	-.763	.695	.399	0.688	-1.791
	(-2.219)	(.930)	(1.876)	(2.095)	(-1.115)
ln (R_I/F)	.042	.332			.622
	(.590)	(2.867)			(.908)
ln (VC/A)		9.484×10^{-3}	.019		
		(.155)	(1.400)		
R^2	.87	.68	.95	.97	.64

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[a] The figures in parenthesis are estimated asymptotic t-ratios; R^2 is the squared correlation coefficient between the predicted and actual values of the normalized variables.

selection of crops that can be grown, some of which do not require irrigation. The elasticity for the Southeast is more than double that of the Northwest and Southwest.

The interregional differences in the estimated elasticity of the quantity of electricity with respect to the price of labor highlights the conflicting forces affecting the relationship between the two variables. The coefficient is not significant in the Midwest. In the Southeast and Texas, labor is shown to be a compliment to electricity. However, in the Northwest and Southwest, increasing labor costs can cause a switch to less labor-intensive and more energy intensive techniques.

The number of irrigated acres per farm is significant in increasing electricity demand per customer in the Midwest. This variable does not make a significant contribution in any other region. Value of crops per acre is positive, but not significant at the .05 level, in the Midwest and Northwest.

The price equation results are shown in Table 4. The equation performs relatively poorly in the Midwest. The use of demand charges for irrigation customers, irrespective of quantity actually used, may be affecting these results. If a consistent series on demand charges could be developed, the performance of this equation may be improved.

The long-run customer equation highlights some revealing regional differences (see Table 5). The average price of electricity is highly significant in all five regions. The lagged customer coefficient varies from a low of .60 in the Southeast to a high of .95 in the Northwest.

It is difficult to observe the effects of some substitute fuels with this model. The price of gasoline and the price of diesel fuel

Table 4. Irrigation Price Equation

Three Stage Least Squares Estimates by Region, 1962-1977[a]

Normalized Variable: PE-C

Variable	Southeast	Midwest	Northwest	Southwest	Texas
Intercept	65.897	15.234	.932	20.511	9.839
	(4.019)	(1.942)	(.372)	(1.374)	(1.929)
E/N	-6.219	-.597	-.110	-0.880	-.998
	(-3.643)	(-1.498)	(-1.133)	(-2.062)	(-1.702)
$(E/N)^2$	.143	3.763×10^{-3}	5.132×10^{-4}	4.926×10^{-3}	.020
	(3.112)	(.999)	(.665)	(1.934)	(1.264)
N	.011	-5.896×10^{-4}	9.315×10^{-4}	4.998×10^{-3}	4.274×10^{-5}
	(.890)	(-.214)	(2.238)	(2.530)	(1.315)
R^2	.59	.22	.78	.88	.72

[a] The figures in parenthesis are estimated asymptotic t-ratios; R^2 is the squared correlation coefficient between the predicted and actual values of the normalized variables.

Table 5. Irrigation Customer Equation

Three Stage Least Squares Estimates by Region, 1962-1977[a]

Normalized Variable: ln N

Variable	Southeast	Midwest	Northwest	Southwest	Texas
Intercept	4.350	-.844	-.037	1.493	.586
	(2.909)	(-.784)	(-.031)	(1.840)	(.311)
$\ln N_{t-1}$	.602	.825	.946	0.788	.762
	(6.682)	(25.886)	(22.879)	(11.845)	(11.706)
ln PE	-.920	-.341	-.098	-0.203	-.254
	(-2.796)	(-3.317)	(-1.533)	(-2.566)	(-2.640)
ln PD	.028	.040	$1.822\text{x}10^{-3}$	0.095	
	(.640)	(1.154)	(.157)	(2.162)	
ln PG			.093		.139
			(1.949)		(3.284)
$\ln R_I$	.086	.223	.018	0.027	.130
	(1.696)	(3.342)	(.256)	(0.540)	(.864)
R^2	.99	.99	.99	.99	.99

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[a] The figures in parenthesis are estimated asymptotic t-ratios; R^2 is the squared correlation coefficient between the predicted and actual values of the normalized variables.

are highly correlated. The multicollinearity makes the independent estimation of their effects on the number of customers impractical.

Diesel fuel appears as a substitute in four of the regions. However, the estimated coefficients are not significant at the .05 level except in the Southwest. In the Northwest and Texas, natural gas appears as a significant substitute. The number of irrigated acres enters with the expected sign in every region and is significant in the Midwest.

The estimated own-price demand elasticities are presented in Table 6. In both the short and long run, the Southwest is the least price responsive, while the Southeast shows the greatest sensitivity to price. For all regions, the short-run elasticity is much larger than is observed for the residential, commercial and industrial sectors.[11]

There is a large difference between the long-run and short-run price elasticities for all regions except Texas. This result highlights the ability of farmers to make adjustments in their use of electricity for irrigation in response to changing prices.

For Texas, the coefficient of average electricity price has a low t-ratio in the demand equation, but it has a high t-ratio in the customer equation. This result points to the interpretation of demand in terms of a choice in power equipment for this region. Once the choice is made, the price does not have much effect upon the quantity of electricity used in the short run.

Table 7 presents the estimated short-run and long-run cross-price elasticities. In the short run, the response to changes in diesel price is relatively inelastic. The Southwest shows the highest long-term adjustment.

Texas shows a relatively high short-run elasticity of demand with

Table 6. Estimated Own-Price Demand Elasticities

Region	Short-run Elasticity	Long-Run Elasticity
Southeast	-2.895	-4.285
Midwest	-1.536	-3.144
Northwest	-1.239	-2.956
Southwest	- .398	-1.153
Texas	- .613	-1.426

Table 7. Estimated Cross-Price Elasticities[a]

Region	Diesel Fuel Price		Natural Gas Price	
	Short Run	Long Run	Short Run	Long Run
Southeast	.028	.070		
Midwest	.040	.229		
Northwest	.002	.034	.093	1.722
Southwest	.095	.448		
Texas			.139	.584

[a] Blanks indicate that elasticities are not estimated.

respect to the price of natural gas. In the long run, the irrigation farmers in the Northwest are highly responsive to changes in the relative price of natural gas, but the short-run cross-price elasticity is relatively small.

CONCLUSION

This examination of electricity demand for irrigation gives a perspective on one of the major components of the demand for energy in agriculture. Irrigation demand for electricity varies widely from region to region, reflecting the great diversity in natural conditions and farming practices across the United States.

The empirical results support the expectation that, in the short run, increasing electricity prices tend to reduce the demand for electricity in all regions. The model highlights the Southeast and Texas as regions in which changing electricity prices will have the strongest immediate impact on demand.

In the long run, the relative price increases of substitute fuels and electricity will determine demand. Even though electricity prices are expected to continue to increase, the prices of oil and natural gas are expected to increase at even higher rates. The model results indicate that such a scenario has potentially dramatic implications for irrigation in some regions. More farmers can be expected to substitute electricity for diesel fuel or natural gas.

Fuel-switching is not the only implication of the long-run analysis. It is also possible to make inferences relating the impact of increasing electricity prices to the level of irrigated agriculture. The significant price elasticities.estimated in this study imply that (1) the cost of electricity is a significant factor in the determination of the amount of irrigation, and (2) farmers would conserve electricity as energy prices continue to increase. Electricity can be conserved in several ways: increased efficiency of the irrigation system which would lead to more water applied per kWh of electricity used; a reduction in the use of water for irrigation through conservation and careful scheduling; and the selection of crops which are less dependent upon irrigation.

Further research on the empirical estimation of the irrigation demand for electricity will consider the sensitivity of the results to different regionalization schemes. The framework of the irrigation submodel described in this paper will be incorporated in a comprehensive analysis and forecasting of the Cooperatives' demand for electricity.

FOOTNOTES

1. Estimates of electricity use for irrigation are from the Federal Energy Administration [1977]; total electricity demand figures are published by Edison Electric Institute [1974].
2. Sloggett [1979] has estimated total irrigated using electricity; Brantwood Publication's "Irrigation Survey" gives total acres irrigated.
3. REA was established by Executive Order in 1935 by President Roosevelt. The Rural Electrification Act of 1936 made statutory provision for REA [Ellis, 1966, pp. 39, 49].
4. For a discussion of the wholesale cost of power to Cooperatives, see Schecter [1966].
5. Production functions for irrigated crops are discussed in Hexem and Heady [1978].
6. For a review of these studies, see King et al. [1978].
7. We appreciate the comments of Joel R. Hamilton, University of Idaho, on this topic.
8. Many farmers do not participate in a conventional market for water. They pay no explicit price per gallon, yet the supply can be limited either through water rights allocations or site availability. Even farmers who pay water fees charged by public or private irrigation districts are not necessarily operating in a competitive market. For example, the projects developed by the U.S. Department of Interior's Bureau of Reclamation do not allow farmers to set value of the marginal product of water equal to the price; instead, fees are charged to reflect the costs of establishing the district and allocations are fixed.
9. For an examination of price and cost relationships for Cooperatives,

see Misesell and Mann [1976].

10. Another approach in modeling long-run demand is to estimate the shares of irrigation farmers using alternative fuels. Such a fuel-share model was developed previously by Baughman and Joskow [1975]. Unfortunately, data availability has prevented the examination of this alternative specification.

11. For a comparison of price elasticities by sector, see Chern et al., [1980] and Maddigan et al., [1980].

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APPENDIX

Data Sources for Variables

Variables	Source(s)
E	a
N	a
PE	a
C	a
AR1D	b
PK	c, d
PL	e
R_I/F	f,d
VC/A	g, d
PG	h
PD	i
PG	i

a. U.S. Department of Agriculture, Rural Electrification Administration, 1961-1978. *Annual Statistics REA Electricity Borrowers.*

b. Strand, Bruce W. 1978. *Monthly Potential and Actual Evapotranspiration, 1931-1977.* Prepared for the U.S. Department of Agriculture, available on computer tape.

c. U.S. Department of Agriculture, Economics, Statistics, Cooperatives Service (USDA/ESCS), 1962-1977. *State Farm Income.*

d. USDA/ESCS, 1962-1977. *Land in Farms and Number of Farms.*

e. USDA/ESCS, 1962-1977, *Farm Labor.*

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f. Brantwood Publications, 1962-1977. "Irrigation Survey." *Irrigation Journal*.

g. USDA/ESCS, 1962-1977. *Value of Crops*.

h. American Gas Association, 1962-1977. *Gas Facts*. Arlington, VA: American Gas Association.

i. USD/ESCS, Crop Reporting Board, 1962-1971. *Agricultural Prices*.