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AGRICULTURAL INPUT USE AND IRRIGATION IN TEXAS*

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ABSTRACT

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In this study, the effect of irrigation on agricultural input use in Texas is considered. Given theoretical and empirical considerations, an input expenditure function is specified which is easily estimable given periodically available agricultural county census data. The model also provides a framework for testing the general hypothesis that irrigation significantly alters the value marginal product (VMP) function for certain agricultural inputs.

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Introduction

Food and fiber production is heavily dependent upon irrigation. It is estimated that more than 28 percent of the total value of United States agricultural crops is produced on irrigated lands (U. S. Department of Agriculture, 1981). Water quality and availability to support this dependence on irrigation is currently a crucial issue in many areas. The quality of water returning to ground water supplies as a result of irrigation run-off is also an important consideration in highly irrigated areas.

A number of studies have considered the economic effects of irrigated agriculture on aquifer depletion and water quality. Studies involving the determination of optimal water withdrawl rates include Bredehoeft and Young (1970), Burt, Cummings, and McFarland (1977), and Hardin and Lacewell (1980). The effects of irrigated agriculture on water quality have been considered for potential pollutants such as nitrates from fertilizers (Ludwick, Reuss, and Langin, 1976). Khan (1982) investigated the effects of irrigation on the accumulation of salts in surface and ground water. This study is concerned with analyzing the effect of irrigation on the use of fertilizer and agricultural chemicals, inputs that have been more intensely used in recent years (Carmen, 1979; Metcalf, 1975) and are potential surface and ground water pollutants (Griffin and Bromley, 1981). It is hypothesized that irrigation may increase the value of marginal product (VMP) of fertilizer and agricultural chemicals. If this hypothesis is true, then future increases in irrigated acreage would lead to increases in the use of these inputs. Subsequently, further and more extensive study regarding the environmental effects of nitrates from fertilizers and potential contaminants from agricultural chemicals may be warranted in areas where irrigation is increasing.

The plan of the paper is to first present a theoretical economic framework for evaluating the impact of irrigation on input use. Second, an empirical model relating agricultural input expenditures to irrigated and non-irrigated acreage is described. Estimation of the model and empirical results for Texas agriculture are then discussed. Next, an analysis of the regional impact of recent increases in irrigated acreage on input expenditures in Texas is presented. Finally, a summary and some conclusions are offered.

Theoretical and Empirical Considerations

The theory of the firm suggests that a farmer selects his input levels for a particular crop from a set of technical production possibilities summarized by a production function:

$$q_j = f_j(r_1, \ldots, r_M) \tag{1}$$

where q_j is the yield of crop j per acre $j = 1, \ldots, N$, and r_i is the quantity of variable input i per acre, $i = 1, \ldots, M$.

The impact of irrigation on input usage may be evaluated by considering particular derivatives of the production function. Specifically, as the amount of irrigation increases, input use would be expected to increase if

$$\frac{\partial^2 q_j}{\partial r_i \partial r_I} > 0 \tag{2}$$

where r_I represents the quantity of irrigation water. If condition (2) holds, then an increase in the use of irrigation will increase the value of marginal product of the i'th input (VMP_i). VMP_i is defined as the addition to total revenue resulting from the use of one additional unit of the i'th input or more formally, $VMP_i = (\partial q_j / \partial r_i) P_j$ where P_j is the price of output q_j. Under competitive conditions (i.e. constant prices) profit maximization will occur when: $VMP_i = w_i$ for all i where w_i is the price of the i'th input. An illustration of optimal input use is shown in Figure 1. If condition (2) holds, then additional irrigation would shift the value marginal product curve to the right such as from $VMP_{i,1}$ to $VMP_{i,2}$. The result would be an

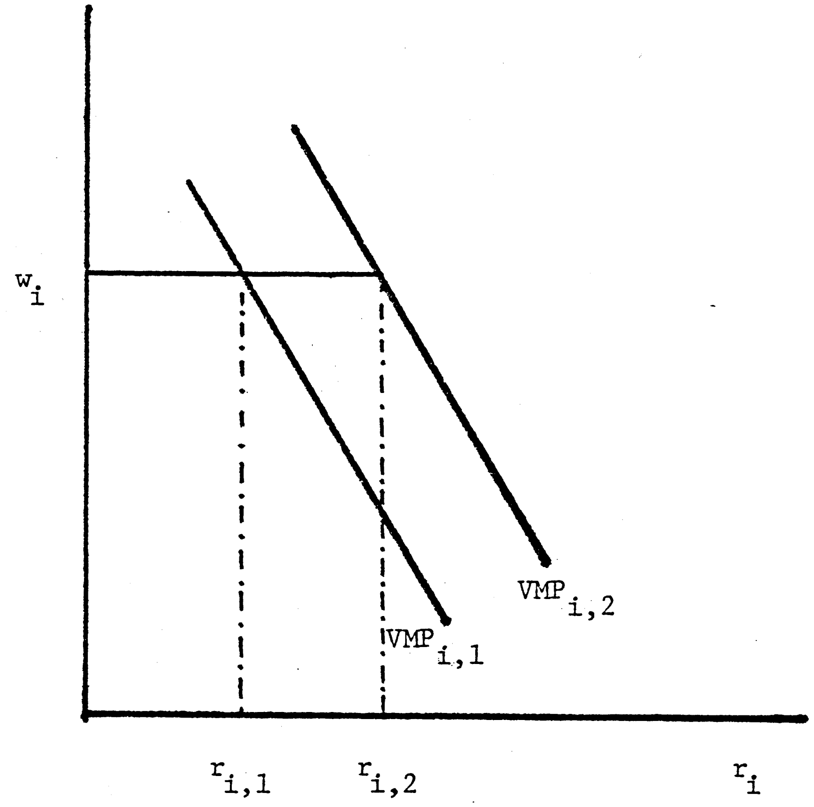

Figure 1. An Illustration of Optimal Input Use

increase in the use of the i'th input from $r_{i,1}$ to $r_{i,2}$, ceteris paribus.

The production function in (1) can be rewritten to reflect fixed land resources and irrigation capacity:

$$q_j = f_j(r_1, \ldots, r_M | S, I) \tag{3}$$

where S is the total agricultural land available and I represents total irrigation capacity. A set of short-run input demand functions can then be derived from the first order conditions for profit maximization. Since S and I are assumed constant during the production period, these equations have the following form:

$$r_i = r_i(P_j, w_i), \quad i = 1, \ldots, M; \quad j = 1, \ldots, N; \tag{4}$$

where the P_j are prices of outputs and the w_i are prices of inputs. The aggregate quantity demanded for an input over all crops, taking into account the presence of irrigation, can be derived as follows:

$$R_i = \sum_{j=1}^{N} r_{ij}^{o} x_j^{o} + \sum_{j=1}^{N} r_{ij}^{*} x_j^{*} \quad i = 1, \ldots, M; \tag{5}$$

where R_i is the aggregate usage of input i and

x_j^o = acres of crop j not irrigated,

x_j^* = acres of crop j irrigated,

r_{ij}^o = quantity per acre of the i'th input on non-irrigated crops for the j'th crop,

r_{ij}^* = quantity per acre of the i'th input on irrigated crops for the j'th crop.

For a given production period the r_{ij}'s could be assumed constant and estimated from cross-sectional data on input use, crop acres under irrigation, and non-irrigated crop acres. The impact of irrigation on input use could then be evaluated by comparing r_{ij}^{o} and r_{ij}^{*}. However, detailed disaggregated empirical data categorized by land use into irrigated and non-irrigated acreage for all major crops is seldom available. In contrast, county data on total acreages of major crops,

$\sum_{j=1}^{N} (x_j^{o} + x_j^{*})$, and total irrigated acreage, $\sum_{j=1}^{N} x_j^{*}$, are periodically

available through agricultural census data. Given these considerations, it is useful to rewrite equation (5) for empirical purposes as follows:

$$(6) \quad R_i = \sum_{j=1}^{N} r_{ij}^{o} x_j + \bar{r}_i \sum_{j=1}^{N} x_j^{*}, \quad i = 1,\ldots, M; \quad j = 1, \ldots, N:$$

where $x_j = x_j^{o} + x_j^{*}$ and $(r_{ij}^{*} - r_{ij}^{o}) = \bar{r}_i$ for all j. Implicitly assumed in equation (6) is the restriction that the difference between input use on irrigated and non-irrigated land, $r_{ij}^{*} - r_{ij}^{o}$, is constant across all crops. Such an assumption is questionable; however, would only be testable given data sufficiently disaggregated to estimate equation (5). In the next section, we discuss an empirical specification based on equation (6).

Model and Estimation

For the empirical application, an expenditure per acre form of equation (6) was used. Multiplying both sides of equation (6) by the input price w_i and dividing by total crop acres, $\sum_{j=1}^{N} x_j$, yields:

$$(7) \qquad y_i = \sum_{j=1}^{N} a_{ij} \bar{x}_j + b_i \sum_{j=1}^{N} \bar{x}_j^{*}$$

where $y_i = w_i R_i / \sum_{j=1}^{N} x_j$ is the total expenditure per acre on input category i divided by total crop acres, $\bar{x}_j = x_j / \sum_{j=1}^{N} x_j$, $\sum_{j=1}^{N} \bar{x}_j^* = \sum_{j=1}^{N} x_j^* / \sum_{j=1}^{N} x_j$, $a_{ij} = w_i r_{ij}^o$ represents the input expenditure per non-irrigated acre on crop j, and $b_i = w_i \bar{r}_i$ represents the difference in input expenditure per acre associated with irrigation. A constant or intercept term is not included in equation (7); if no crop acres were planted, no variable inputs would be used.

As an empirical example, Texas agriculture was chosen given the relative importance of irrigation in the state. Irrigated lands account for more than 60 percent of the total value of agricultural crops produced in Texas (Knutson, et al., 1977). The input categories of interest in this study are total fertilizer expenditures and total expenditures for agricultural chemicals. The equations estimated can be written:

$$y_h^f = \sum_{j=1}^{8} a_j^f \bar{x}_{jh} + b^f \bar{x}_h^* + u_h^f \tag{8a}$$

$$y_h^c = \sum_{j=1}^{7} a_j^c \bar{x}_{jh} + b^c \bar{x}_h^* + u_h^c \tag{8b}$$

where for the h'th county, h=1, ..., H,

y_h^f = total fertilizer expenditures per acre,

y_h^c = total chemical expenditures per acre,

x_{1h} = acres in upland cotton,

x_{2h} = acres in grain sorghum,

x_{3h} = acres in corn,

x_{4h} = acres in rice,

x_{5h} = acres in vegetables,

x_{6h} = acres in legumes (soybeans and peanuts),
x_{7h} = acres in alfalfa,
x_{8h} = acres in other hay,
x_h^* = total irrigated acres,

the a's and b's represent parameters to be estimated, and the u's are random disturbances assumed to be normally distributed with zero means and constant variances σ_f^2 and σ_c^2. It is also assumed that u_h^f and u_h^c may be contemporaneously correlated so that $E(u_r^f u_s^c) = \delta_{rs}\sigma_{fc}$ for r, s = 1, ..., H where σ_{fc} represents the covariance between the two error terms u_h^f and u_h^c and δ_{rs} is the Kronecker delta that is unity if r = s and zero otherwise. In other words, disturbances in the expenditure equations may be correlated within counties but not between counties. Such an assumption seems reasonable since a farmer's input decisions are probably made jointly, but his or her actions are not likely affected by the input decisions of farmers in other counties. Given these assumptions on the error terms u_h^f and u_h^c, the seemingly unrelated regression estimator (Zellner, 1962) was used to derive parameter estimates for equations (8a, b). For estimation purposes counties in Texas which reported no crop acres were not considered in the analysis, resulting in a total of 245 available observations. Other hay production was not included in the agricultural chemicals equation since only fertilizer is systematically applied on all acres planted in hay. Data for the analysis were from the 1978 agricultural county census (Census of Agriculture, 1979).

Results

Empirical estimates of the parameters in equation (8) appear in Table 1; standard errors appear in parentheses. The coefficient estimates can be

Table 1. Empirical Estimates of Input Expenditure Equations for Texas, 1978

Independent Variable	Equation Coefficeints	
	Fertilizer	Chemicals
X_1	3.68	3.08*
	(2.37)	(1.84)
X_2	2.49*	6.19**
	(1.38)	(1.04)
X_3	21.55**	4.59
	(8.99)	(6.89)
X_4	18.21**	13.31*
	(8.95)	(6.92)
X_5	16.91	36.55**
	(12.65)	(9.67)
X_6	19.19**	16.15**
	(6.06)	(4.54)
X_7	19.68**	23.79**
	(9.56)	(7.38)
X_8	53.63**	---
	(2.04)	---
X^*	10.66**	5.11**
	(2.62)	(2.00)

Dependent variable = input expenditure per acre

Total number of observations = 245

Weighted R^2 for system = .75

*Significantly different from zero at $\alpha = .1$ level.

**Significantly different from zero at $\alpha = .05$ level.

interpreted as the impact of a one-acre increase of land for a particular crop use on the expenditures for a particular input category. All estimated coefficients are significantly different from zero at usual significance levels except those for cotton and vegetables in the fertilizer equation and corn in the chemicals equation. In particular, the coefficient associated with irrigated acreage is significantly different from zero in both equations and indicated a \$10.67 higher fertilizer expenditure per acre on irrigated versus non-irrigated land and a \$5.12 higher chemicals expenditure per acre on irrigated land. These results support the hypothesis that irrigation increases the VMP of certain farm inputs, specifically for fertilizer and agricultural chemicals in Texas.

The above results were used to determine the effect of irrigation on total catagorical input expenditures for the ten major production regions in Texas (see Figure 2). Referring to Table 2, absolute dollar figures represent the amount of expenditures attributable to irrigation computed by multiplying the total irrigated acreage in each region by the expenditure derivatives above: \$10.67 for fertilizer and \$5.12 for agricultural chemicals. Percentage figures in parentheses represent the ratio of the amount of input expenditures attributable to irrigation to the total amount of input expenditures for the region. The largest estimated expenditure effects occured in areas of intensive irrigated agriculture such as the High Plains and Trans-Pecos (regions I and VI). For the state, it is estimated that 22.2 percent of total fertilizer expenditures and 21.3 percent of total expenditures for agricultural chemicals were accounted for by irrigation in 1978.

The regression results were also used to estimate the impact of recent changes in irrigated acreage on total fertilizer and agricultural chemical expenditures in Texas. For this part of the analysis, the changes in irrigated acreage by production region for the period 1974 to 1978 were multiplied by the estimated impact of irrigation on input expenditures per acre; \$10.67 for fertilizer and \$5.12 for agricultural chemicals. These results are presented in Table 3. All but two regions, II and VI, showed increases in irrigated acreage over the 1974-1978 period. The largest increase was in Region I resulting in estimated annual increases due to irrigation of approximately \$2.35 million and \$1.13 million for total fertilizer and agricultural chemicals expenditures respectively. For the state, the annual changes in input expenditures due to increased irrigation for 1978 relative to 1974 were approximately \$3.66 million for fertilizer and \$2.27 million for agricultural chemicals. These figures represent percentage

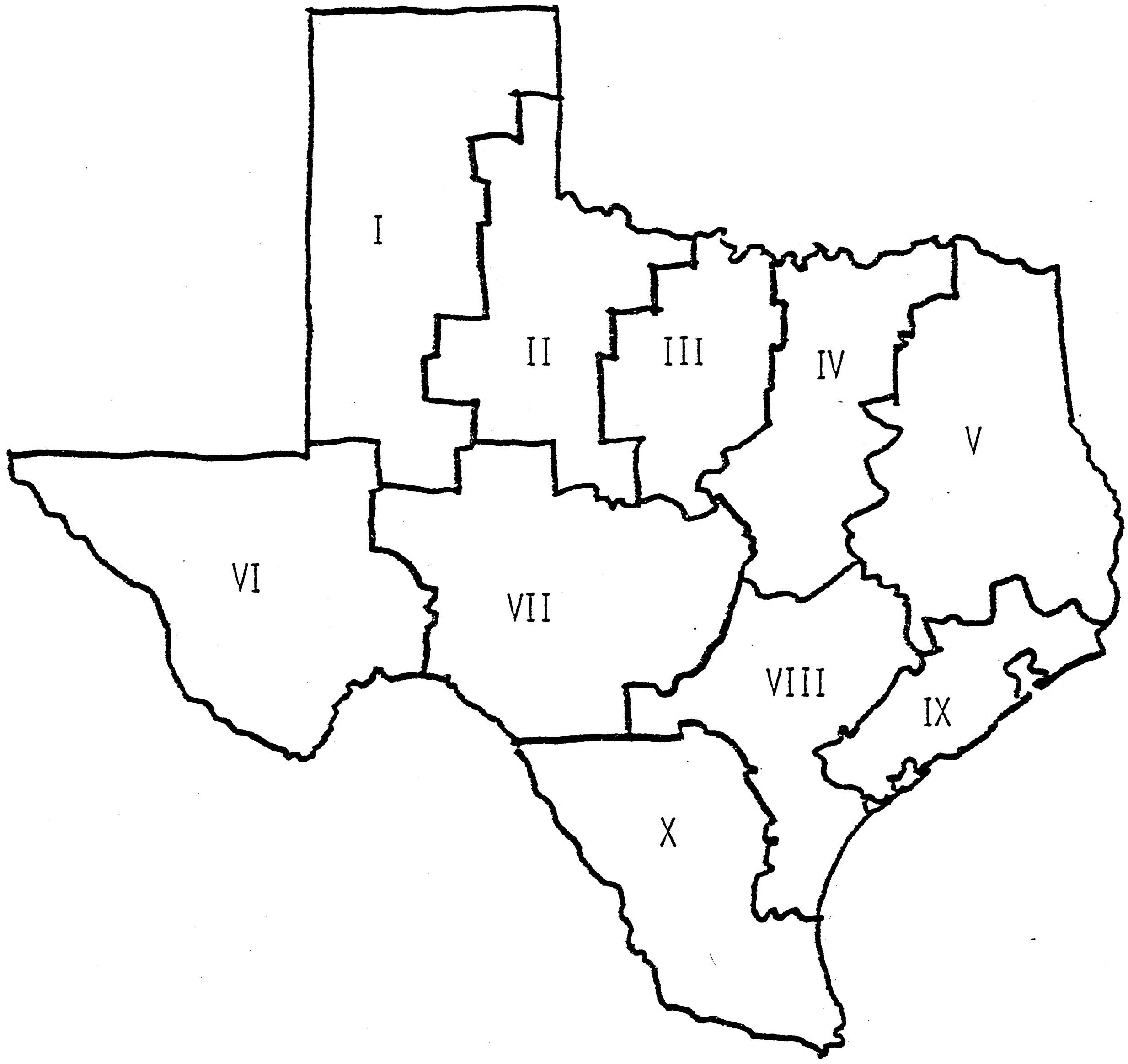

Figure 2. Major Production Regions in Texas

Table 3. Impact of Increased Irrigation on Annual Input Expenditures in Texas, 1974-1978. ($1000)

Input	Region										Total
	I	II	III	IV	V	VI	VII	VIII	IX	X	
Fertilizer	2,346.36	9,595.3	5,774.0	3,064.0	7,862.3	-5,396.01	4,955.43	3,270.9	4,042.07	7,732.20	$3,659.92
Chemicals	1,126.24	4,605.7	-2,771.5	1,470.7	3,773.8	-2,590.06	2,778.58	1,570.0	1,940.17	3,711.42	$2,274.75
TOTAL	3,472.61	1,420.1	-8,545.6	4,534.8	1,163.61	-7,986.07	7,334.02	4,841.0	4,982.25	1,144.36	$5,934.68

Table 2. Impact of Irrigation on Input Expenditures for Texas, 1978. ($1000)

	Region										
Input	I	II	III	IV	V	VI	VII	VIII	XI	X	TOTAL
Fertilizer	50,736.2 (54.3%)	1,948.2 (12.0%)	855.9 (5.3%)	379.4 (.3%)	686.8 (1.7%)	1,607.3 (51.0%)	1,520.2 (24.9%)	1,853.3 (4.4%)	6,101.2 (16.9%)	8,179.3 (32.6%)	$73,867.8 (22.2%)
Chemicals	24,353.1 (47.3%)	935.1 (7.4%)	410.8 (6.9%)	182.1 (2.0%)	329.6 (2.9%)	771.5 (44.5%)	729.7 (14.6%)	889.5 (5.8%)	2,928.5 (13.4%)	3,926.0 (14.7%)	$35,455.9 (21.3%)

increases of 7.8 percent and 2.8 percent for total state fertilizer and agricultural chemicals expenditures, respectively, due to increases in irrigated acreage over the 1974-1978 period.

Summary and Conclusions

In this study we have considered the effect of irrigation on agricultural input use in Texas. Given theoretical and empirical considerations, an input expenditure function was specified which is easily estimable given periodically available agricultural county census data. The model used also provides a framework for testing the general hypothesis that irrigation significantly alters the VMP for certain agricultural inputs. For the case of Texas, results indicated that increased irrigation is accompanied by greater expenditures for both fertilizer and agricultural chemicals. Based on these results a regional analysis of the impact of recent changes in irrigated acreage on input expenditures was performed.

The methodology presented in this paper appears useful in that the relationship between irrigation and agricultural input use can be easily investigated. It is arguable that more useful results could be obtained in situations where more disaggregated data were available. For instance, crop-specific data on input use under both irrigated and dryland conditions would undoubtedly yield more refined estimates regarding changes in input use associated with irrigation. However, since such data are usually not available, the more aggregated approach suggested here might be useful in determining whether or not input use is significantly affected by irrigation. If a significant relationship is suspected, a further more disaggregated analysis may be warranted.

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