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A COMPARISON OF AGRICULTURAL NET RETURNS AND REGIONAL HOUSEHOLD RECEIPTS UNDER ALTERNATIVE STRATEGIES OF GROUNDWATER DEPLETION*

by

James E. Casey, Lonnie L. Jones, and Ronald D. Lacewell**

ABSTRACT

The agricultural producers of the High Plains of Northern Texas and Western Oklahoma are faced with the prospect of inadequate groundwater supplies to sustain future agricultural production. It is expected that given decreasing water levels the extraction costs or physical capacity of the wells will prohibit bringing additional acres under irrigation and ultimately force reductions in the number of irrigated acres. This paper presents an innovative regional model for evaluating alternative strategies of utilizing the existing groundwater supplies.

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The Northern High Plains of Texas and Western Oklahoma has experienced rapid economic development due primarily to the development of groundwater for irrigation. Prior to irrigation development, this area of Texas and Oklahoma was devoted primarily to grazing and dryland production of some agricultural crops. Irrigational development encouraged rapid growth in agricultural production. As a result, the agricultural industry became the economic base for the entire region. Service industries to provide inputs and goods and services to the agricultural production sector have also increased in the region. Currently, the agricultural sector is continuing to lead the High Plains regional growth and the irrigated production is a major component of the region's agricultural production.

The primary source of irrigation water in the High Plains of Texas and Oklahoma is the Ogallala underground acquifer. Geohydrological data indicate that groundwater is being withdrawn more rapidly than its' being replaced. If current use rates continue the groundwater will be economically depleted for irrigation within the next 25 to 40 years.

As groundwater levels fall, due to increased costs of extraction, production costs per acre increase. The present trend is to increase the number of wells and irrigated acres which aggravate the depletion problem. Ultimately, depletion of the acquifer will prohibit the addition of irrigated acres and in fact force reductions in the number of irrigation acres (Wyatt).

The impending reduction in irrigation activity will decrease the producers.

demand for inputs complementary to irrigation and lower producer net returns. The reduction in producer net returns is a direct reduction in regional income. An indirect reduction in regional income results as producers' demands for inputs decrease thus decreasing the net returns to the industries providing goods and services to the agriculture sector. Legal controls have been suggested to influence the rate of withdrawal of groundwater. These include restricting withdrawal, restricting the number of new wells, and taxing water use. However, without projections on the effects of water shortages, it is difficult to effectively evaluate alternative policy proposals.

The primary objective of the study is to estimate regional economic adjustments in response to expected changes in groundwater use for irrigation. This paper includes two concepts as a small subset of total results of the study. First, producer net returns from agricultural production and, secondly, the regional household receipts resulting directly and indirectly from that agricultural production.

This study focuses on the interrelationships among industries in the area, including agricultural industries, and projects adjustments that potentially arise due to the limitation of irrigation water. Both the positive and normative approaches have been taken to estimate the regional adjustments. Typically, input-output analysis have been used to describe the regional economy. Changes in output of the agricultural sector or the final demand sectors are injected into the model and traced through the interdependencies. Model results include the changes in output of all regional sectors due to the changes introduced into the model. In contrast, linear programming has been used for analyses of the agricultural sector, both on the micro or macro level. Model results are usually estimating changes in cropping patterns, output, and returns due to varying assumptions in water availability. The use of various models, whether input-output or linear programming, has been independent research with other research efforts used only for reference. This paper presents the results of a research effort which integrated the positive and normative approach and allows for interaction of the two above mentioned models.

Methodology

Several approaches were considered before the model to be presented was finalized. A standard input-output model was considered, but did not allow for the desired allocation of water.[1] A regional linear programming model would provide estimates of agricultural adjustment due to limited quantities of water. However, this approach did not provide for estimation of regional effects in non-agricultural sectors and this was one of the major objectives of this study. A feasible alternative was to input the linear programming output results into an input-output matrix and estimate the non-agricultural sectoral output adjustments. A major limitation of this approach is that the agricultural sector is an integral part of the regional input-output model. Any independent analysis of the agricultural sector did not allow for the interrelationships that exist between the agricultural and non-agricultural sectors. The ultimate model incorporates an input-output description of the regional economy into a recursive linear programming scheme. The interdependencies in the input-output segment actually perform as constraints in the linear programming model.

Figure one is a diagrammatic representation of the entire model which shows the different segments that incorporate the input-output model. Block A includes the agricultural sectors and the resource constraints to the agricultural activities. The objective function of the agricultural segment of the model is to maximize producer net returns subject to certain resource constraints. Algebraically, this segment of the model is written as:

Figure 1: A diagrammatic representation of a regional model to estimate the economic adjustments due to an exhaustible groundwater supply[1]

		Agriculture Production Activities[2] (X = 1, . . . m)				Input - Output Processing Sectors (Non Agricultural) (X = m, ... 42)				Final Demand		Model Constraints
		X_1^A	X_2^A		X_m^A	X_{m+1}^P	X_{m+2}^P	. . . .	X_{42}^P	X_1^Y	$X_2^Y \ldots X_{42}^Y$	
Resource Restrictions	OBJF[4]	C_1X_1 +	C_2X_2 +	. . . . +	C_mX_m							$\leq q_1$
	SUBJECT TO:	$a_{11}X_1$ +	$a_{12}X_2$ +	. . . . +	$a_{1m}X_m$							$\leq q_2$
	A	$a_{21}X_1$ +	$a_{22}X_2$ +	. . . . +	$a_{2m}X_m$							$\vdots$
		$\vdots$										$\vdots$
		$a_{m1}X_1$ +	$a_{m2}X_2$ +	. . . . +	$a_{mm}X_m$							$\leq q_m$
Input-Output Processing Sectors	X_1	$(1-V_{11})X_1^A$ -	$V_{12}X_2^A$ -	. . . . -	$V_{2m}X_m^A$ -	$b_{1,m+1}X_{m+1}^P$ -	$b_{1,m+2}X_{m+2}^P$ -	. . . . -	$b_{1,42}X_{42}^P$	$-X_1^Y$	0.....0	= 0
	X_2	$-V_{21}X_1^A$ +	$(1-V_{22})X_2^A$ -	. . . . -	$V_{2m}X_m^A$ -	$b_{2,m+1}X_{m+1}^P$ -	$b_{2,m+2}X_{m+2}^P$ -	. . . . -	$b_{2,42}X_{42}^P$	0	$-X_2^Y$ 0	= 0
	$\vdots$ B[3]	$\vdots$					C			$\vdots$		
	X_{42}	$-V_{42,1}X_1^A$ -	$V_{42,2}X_2^A$ -	. . . . -	$V_{42,m}X_m^A$ -	$b_{42,m+1}X_{m+1}^P$ -	$b_{42,m+2}X_{m+2}^P$ -	. . . . . . +	$(1-b_{42,42})X_{42}^P$	0	0 .....$-X_{42}^P$	= 0

[1] The principal purpose of the diagram is to illustrate the linkage of the input-output interrelationships to a regional linear programming model.

[2] All the X_j's represent activities in the linear programming model. The superscripts A and P are used to denote agricultural production sectors and non-agricultural production sectors.

[3] In segment B the principal diagonal is not a straight line due to the scale, on which sector one through 42 are shown.

[4] Objective function values include net return for the agricultural production sectors and zero for the non-agricultural production sectors.

$$\text{Max } z = C_1X_1^A + C_2X_2^A + \ldots\ldots + C_mX_m^A \qquad (1)$$

Subject to:

$$\Sigma\, a_{ij}X_i \gtrless q_i \qquad (2)$$

Where:

C_j is the net returns for agricultural production activity X_i.

X_j represents agricultural production activities. The X_j's represent activities in the linear programming model with $j = 1, \ldots m$ for agricultural activities.

a_{ij} is the amount of resource i used by agricultural activity j.

q_i is a vector of right-hand side restraints.

The agricultural production sector is only a part of the overall model. The structure of the High Plains economy, as described in the input-output model, is an integral part of the model. This section of the model, segments B and C in figure one, estimates the changing economic activity of industries that directly or indirectly support agriculture. Input-output and linear programming are both linear models and can be integrated into one model such that the input-output model becomes a part of the constraint set of the linear programming routine.

The direct coefficients matrix of an input-output model provides the mechanism to integrate the input-output matrix directly into the linear programming model. In matrix notation the direct coefficients table is represented by:

$$B X + X^y = X \qquad (3)$$

Where:

B is a 42 x 42 matrix of technical coefficients for the processing sectors of the High Plains. Any element of B (b_{ij}) is less than one and greater than or equal to zero.

X is a vector of the output of the processing sectors (agricultural and non-agricultural) in the input-output model of the High Plains of Texas and Oklahoma. The elements, X_i, of X range from one to n with $j = m, \ldots n$ for non-agricultural production sectors.

X^y is a column vector of sales to final demand for each of the processing sectors in the High Plains economy.

The matrix formulation of equation 3 is compatible with the algebraic formulation of the constraints in segment A. Vector X of the output of the processing sectors corresponds to the vector of activities in the linear programming format. The elements, b_{ij}, of matrix B are equivalent to the a_{ij} coefficients in segment A of the model. Similarly, the vector of the final demand corresponds closely to a vector of right-hand side restrictions. The interdependencies expressed by the input-output model are used to estimate the economic activity necessary to support the output of the High Plains agricultural industry at levels estimated in segment A of figure one. The input-output segment operate similar to transfer rows in that if an agricultural activity is initiated then the amount of output required from other sectors is estimated by the input-output relationships.

The coefficients of the input-output model are reformulated to fit the form of typical linear programming constraints and are treated as transfer rows. Equation 3 is transformed into the following two equations:

$$X - BX = X^y \qquad (4)$$

$$(I - BX) = X^y \qquad (5)$$

Where:

I is an identity matrix defined as having the value one on the principal diagonal and zeros elsewhere, in the matrix.

In algebraic notation, the first row of the matrix notation of equation 5 is as follows:

$$(1-b_{11})X_1 - b_{12}X_2 - \cdots\cdots - b_{1,n}X_n = X_1^y \qquad (6)$$

One further operation is needed to use equation 6 as a linear programming constraint in this model. In equation 7 final demand is brought to the left side of the equality and the entire equation is set equal to zero.

$$(1 - b_{11}) X_1 - b_{12}X_2 - \cdot\cdot\cdot\cdot\cdot - b_{1n}X_n - X_1^y = 0 \quad (7)$$

The format of equation 7 is due to the objective of the model which is to estimate the level of economic activity of non-agricultural sectors necessary to support the estimated levels of output in the agricultural sector. As one unit of activity in the agricultural sector is initiated in the model, increased output is required in all related sectors to support production of the agricultural sector. The increases in output of the supporting sectors also require secondary and tertiary output increases from other related sectors. The inclusion of a set of equations such as equation 7 as transfer rows allows the multiplier effect to be estimated as an integral part of the model solution.

As indicated earlier, certain data transformations are required to directly link linear programming and input-output sections of the model. The direct effects of agricultural sectors on other sectors are found in Block B of figure one. Rows in Block B correspond to rows in the input-output model, however, columns in Block B correspond only to columns in agricultural sectors. In figure one the X_j's represent activities in the linear programming format. The X_j^A denote agricultural production activities (i.e. j = 1, . . . m) and X_j^P denote non-agricultural production activities (i.e. j = m, . . . n). Any column in Block B estimates the value of purchases of that agricultural sector from each of the other sectors. However, an adjustment to the input-output direct coefficients is needed in segment B. Direct coefficients in the initial input-output model are estimates of purchases from all sectors per dollar of output by the purchasing sector. Processing sectors sell to the agricultural sectors which are entered in

Block A on a per acre basis. Hence, coefficients in Block B are adjusted to purchases per acre rather than purchases per dollar. Equation 12 is the computation formula for estimating the adjusted coefficients in Block B:

$$V_{ij} = GVP_j \quad (b_{ij}) \qquad (12)$$

Where:

V_{ij} = the adjusted coefficients that estimate the value of purchases of sector j from sector i for an acre of production of sector j.

GVP_j = the gross value product of one acre of production of sector j.

Results

Results of the overall model include agricultural output, net returns, and cropping patterns , regional employment, non-agricultural output, and regional household receipts (Casey). The latter three categories are not regional totals, but rather total necessary to support the agricultural production estimated in the model. The scope of the results reported herein is to look only at producer net returns and regional household receipts.

The producer net returns are estimated by the agricultural segment of the model. Similarly, the household receipts are estimated by the input-output accounting system which is an integral part of the overall model. Since the two estimates are attained from the same model runs under identical assumptions it is useful to draw some comparisons.

In order to compare producer returns and household receipts three different assumptions on groundwater development are evaluated. The initial strategy assumes that groundwater withdrawal will continue along historical patterns as estimated from data of previous years. An alternative strategy assumes that the rate of groundwater development is accelerated therefore peak pumpage would be reached in an earlier year. The third strategy assumes that an institutional type constraint is imposed at the 1980 level of pumpage from the Ogallala.

Producer Net Returns

An internal rate of return of eight percent is assumed for comparison of alternate streams of producer net returns. At an internal rate of eight percent, High Plains agricultural producers realize a greater present value of returns under the faster irrigation development strategy. Total estimated present value of net returns over the 35 years period is \$3.512 billion for the higher development strategy compared to \$3.392 billion under the slower strategy (Table one). Total present value of producer net returns are also greater under the current rate of irrigation development compared to the institutional restriction (\$3.463 billion compared to \$3.392 billion). This implies that the regional producers who wish to maximize the present value of returns would prefer a strategy of increasing the rate of groundwater withdrawal as opposed to a slowdown of withdrawal. The difference between present value estimates under the current development strategy and the slower development strategy is the potential loss to producers if institutional constraints are imposed. If such an institutional restriction is imposed the present value (at 8%) of unrealized producer net returns is an estimated \$71 million.

A discount rate of 3.25 percent is also used to evaluate producers discounted income.[2] The present values of future producer returns from the alternative irrigation strategies are reversed under the lower discount rate.

These results indicate that if the discount rate were to decrease a point would be reached where producers would shift their preferences toward strategies of groundwater development.

A systematic search routine is used to estimate breakeven discount rates which show the discount rate where the producer is indifferent between two

Table 1: Estimates of producer net returns and regional household receipts under three strategies of irrigation development: High Plains of Texas and Western Oklahoma.

	Producer Net Returns[1]			Household Receipts[2]		
Year	Current	Slower ($1,000,000)	Higher	Current	Slower ($1,000,000)	Higher
1975	256.0	256.0	256.0	519.4	519.4	519.4
1980	262.9	262.9	278.7	532.1	532.1	561.7
1985	280.0	263.9	297.6	564.4	534.2	595.0
1990	298.6	295.9	264.8	597.6	536.2	593.3
1995	291.8	265.5	289.7	486.9	537.7	582.9
2000	286.4	266.0	283.5	577.1	538.9	571.5
2005	278.9	266.5	275.9	563.1	540.0	557.5
2010	271.3	267.0	NA	549.0	541.0	NA
Discounted @ 8%	3463.4	3392.7	3512.7	6991.2	6392.6	7072.6
Discounted @ 3.25%	6032.1	6120.9	5960.5	12166.4	12400.7	1196.7

[1] The producer net returns are estimated from the projected agricultural production under each of the three strategies.

[2] The regional household receipts are these receipts which result directly or indirectly from the corresponding year's agricultural production.

strategies. At an estimated discount rate of 4.5 percent producers of the region would be indifferent between the current irrigation development and the slower irrigation developments. This implies that the internal rate of return would have to decrease to less than 4.5 percent before agricultural producers would be willing to support institutional restrictions to groundwater withdrawal.

At an internal rate of return of 4.7 percent, producers in the region are indifferent between the faster irrigation development and the slower irrigation development. At any discount rate of greater than 4.7 percent the producers prefer a strategy of rapid withdrawal of the groundwater.

The only discount rate where producers would prefer the current irrigation development is estimated at 4.6 percent. This seems to imply that the actual discount rate is approximately 4.6 percent for High Plains producers. However, this is not necessarily the case due to certain characteristics constraints in the High Plains to developing irrigation as fast as possible. Due to a high degree of risk and uncertainty in agricultural production the High Plains producers are reluctant to make extensive capital investments necessary for "all out" development of irrigation. In addition, there are physical engineering constraints to a rapid increase of irrigation development.

Regional Payments to Households

At a discount rate of eight percent the highest present value of regional payments to households is under the faster irrigation development rate. Total present value of payments to households is $7.07 billion under the faster irrigation development compared to $6.99 billion under the current rate and $6.39 billion under the slower irrigation development rate (Table one).

Regional payments to households are also discounted at rate of 3.25 percent. Annual and total estimates of discounted receipts are an estimated

$12.4 billion under the slower development compared to $12.0 billion for the higher rate of development and $12.2 billion under the current rate. A conflict of interest arises as the present value of returns to the High Plains regional economy indicates preference for opposite groundwater withdrawal stragegies at discount rate of 3.25 percent and 8 percent.

Breakeven discount rates are estimated which equate the present value of payments to households for two irrigation development strategies. Total discounted household receipts are equated for the faster and slower development strategies at a discount of 5.1 percent. At any social discount rate above 5.1 percent society realizes greater present value under the strategy of rapid depletion of the groundwater. At any social discount rate below 5.1 percent society has an interest to institutionally restrict the withdrawal of groundwater. The lower discount rate is representative of a social rate while the higher rate is more representative of a private rate of return. Therefore, the results indicate that producers and society prefer different strategies of groundwater withdrawal.

Conclusions

The model reported is an example of integrating two standard, but usually independent, techniques to develop a more meaningful approach to regional linear programming. Typically, regional linear programming models do not reflect the structural interdependencies that exist within a region. These interdependencies modify the overshifting to one or two activities that is typical of linear programming analysis.

The model results reported in this paper verify that area producers and society prefer opposing strategies of irrigational development. The internal rate of return would have to decrease and the social discount rate increase before the two points-of-view would coincide. The model estimates the difference in present values of different strategies. These differences should be useful to policy makers in estimating the total tax base that could be used to compensate producers if the lower strategy was imposed.

FOOTNOTES

*Technical article of the Oklahoma State University Agricultural Experiment Station and technical article of the Texas Agricultural Experiment Station.

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[1] An input-output approach using a simulation model was used at Oklahoma State University in a separate, but related phase of the overall research effort (Eckholm, Schreiner, and Eidman).

[2] The discount rate of 3.25 as chosen is to represent a typical social discount rate. The rate corresponds to the rate used in recent governmental projects.

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