Estimating Regional Output Response to an Exhaustible Natural Resource

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

Agriculture in the High Plains of Northern Texas and Western Oklahoma contributes significantly to the economy of that region [Eckholm; Grubb; Osborn]. This region is characterized by highly intensified and commercialized agricultural production sectors. Twenty-three counties in the Texas Panhandle and the three county tier in Western Oklahoma includes over six million acres devoted to agricultural production of which over four million are irrigated.

Estimates show that irrigation increases average yields of wheat, cotton, and other crops. Corn production is considered feasible only under irrigation. Thus, irrigated agriculture is a basic industry of the economy that has experienced rapid growth in recent years.

This increase in the number of irrigated acres expands producers' demand for productive inputs thus increasing production in non-agricultural sectors. Producers realize greater incomes which increase their demand for consumptive goods and services. The agricultural production sectors of the High Plains purchase directly from non-agricultural sectors such as agricultural services, chemicals, petroleum products, and finance sectors. Sectors that sell goods and services to agricultural production sectors also purchase goods and services from other sectors of the economy. Thus, secondary output effects are related to the increased productivity of the agricultural production sectors. However, economic growth based on irrigation cannot be assumed continuous in the region since the groundwater supply is exhaustible. The purpose of this paper is to present methodology for estimating economic adjustments in non-agricultural sectors that may be expected to occur as groundwater inventories in the study area are depleted. An example of the results generated by model application to the study area are presented.

James E. Casey is an assistant professor, Department of Agricultural Economics, Oklahoma State University, and Lonnie L. Jones and Ronald D. Lacewell are associate professors, Department of Agricultural Economics, Texas A&M University.

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Groundwater as a Limiting Factor

The Ogallala acquifer supplies water for irrigation in the High Plains region. Natural recharge in the Ogallala is estimated to be only one-half inch per year [Osborn]. Current appraisals show approximately 340 million acre-feet of groundwater stored in the portion of the Ogallala that underlies the High Plains region. Between five and six million acre-feet of groundwater are mined from this region annually. As the groundwater levels decrease, the costs of extraction rise resulting in increased production costs per acre. Although irrigated acres are currently increasing in the area, at some future time the cost and/or capacity of wells will prohibit bringing additional acres under irrigation and ultimately force reductions in the number of irrigated acres [Wyatt].

As the cost of pumping each unit of irrigation water rises, producers may be expected to adjust cropping patterns in an effort to maintain net returns. Expected adjustments in cropping patterns are 1) shifts to crops which use relatively less water while maintaining the highest net returns, 2) reducing the number of irrigations and 3) a switch to non-irrigated production.

As the level of irrigation declines, producers' demand is reduced for inputs complementary to irrigation, such as nitrogen fertilizer, chemical pesticides, and labor. Budgets constructed for primary crops in the study area show significant reductions in producer net returns and input purchases when irrigation is reduced. As the extraction of the groundwater becomes economically infeasible the entire regional economy is expected to experience contraction in output.

Interfacing Linear Models

A regional linear programming model of the agricultural segment of the economy is used to estimate producer adjustments. Results of this model indicate the adjustments in cropping patterns and producer net returns that are expected as the groundwater is depleted. In addition, a regional information system is included to estimate adjustments in output of the non-agricultural sectors. The output modifications estimated for non-agricultural sectors are in response to changes in output of the agricultural sectors of the regional economy.

Regional Programming Model

A regional programming model is developed to allocate the groundwater resource among competing agricultural sectors. The model is composed of two major segments, an agricultural production segment and a non-agricultural response segment. The agricultural segment of the model is an activity analysis of production agriculture in the region.

The activity analysis includes production alternatives for each of the major crops grown in the region. Since the use of groundwater is of primary interest, each crop production activity is partitioned into different levels of irrigation. Various levels of irrigation, including dryland, or non-irrigated, are incorporated to estimate cropping pattern adjustments as groundwater becomes a limiting factor in the production process.

Groundwater availability is the dominant resource restriction in the activity analysis. Estimates of groundwater availability are based on projected rates of pumpage from the Ogallala [Wyatt]. The rates of pumpage are dependent on changing well capacity and the rate of developing new wells. Thus, well capacity and the rate of new well development become an effective constraint to groundwater use in the High Plains region. This specification is consistent with the conditions that exist in the region. Typically, producers have been unable to apply groundwater to the profit maximizing point on an annual basis considering only variable costs of pumping (i.e., marginal value product of water equal to price of water) due to limits on well capacity, rather than capital constraints.

Secondary constraints to the model include cropland restrictions which allow for reasonable estimates of the region's production capacity. Similarly, feedlot capacity is constrained to the levels consistent with the region's feedlot activities.

Regional Information System

The non-agricultural response segment of the model is a regional information system which is used to estimate output of non-agricultural sectors in response to output of agricultural sectors. The methodology necessary for the information system is provided by a High Plains input-output model [Osborn]. The relationships among sectors, as described by the input-output structure, is integrated into the activity analysis segment of the regional model.

Input-output and linear programming are both linear models which allow for interfacing of the two models such that the input-output model becomes a part of the constraint set of the linear programming routine.[1]

In addition to accounting for output changes of non-agricultural sectors, the inclusion of the sector interdependencies has other analytical advantages. Since indirect linkages are included in the model solution, the optimal cropping pattern configuration suggested by the model differs from the corresponding configuration in the absence of such linkages. Typical regional linear programming analysis of the agricultural sector ignore such economic sector interdependences and their influence on adjustments within agriculture.

Temporal Characteristics

The overall programming model is structured in a recursive scheme that allows for changes over time in groundwater pumpage. Estimates of groundwater pumpage over time are available and based on recent trends of irrigation well development in the region.

[1] A detailed description of the model is available from the authors.

Changes in groundwater availability over time for irrigation development do not follow a linear trend. Therefore, typical parametric procedures are not applicable. Instead, an extension of linear programming is utilized which consolidates a Fortran program with the linear programming framework. The Fortran model functions as a subroutine which modifies the linear programming tableau for subsequent solutions. Interfacing of Fortran and linear programming is adapted in this model for evaluating the changing water availability as irrigation develops. A non-linear vector of groundwater availability is inputed into the model. The model yields optimal solutions for each of the groundwater availability levels without the normal manual operations required in a recursive model.

Results

The activity analysis provides estimates of production adjustments that are expected as groundwater becomes a limiting factor. Results of the activity analysis are not present herein, rather an example of the estimation of non-agricultural response output is presented. The non-agricultural sectors produce in response to the level of agricultural production, thus the aggregate value of agricultural output is needed to determine the sectoral production. In 1975, 1990, and 2005 the value of agricultural production is estimated at $1.48 billion, $1.72 billion, and $1.68 billion, respectively.

Presented in table 1 are estimates of employment, household receipts, and non-agricultural output that result due to agricultural production. Data are presented for 15-year intervals, from 1975 to 2005. The five sectors of the High Plains that show greatest response to agricultural activity are reported along with totals for all non-agricultural sectors. Output reported in table 1 is response output and represents only that sector's output necessary to support the agricultural activity in the region. Similarly, estimates of employment and households are only totals induced by agricultural production.

Sectoral Output

The output of the non-agricultural sectors follows the basic pattern as that of water availability in the study area. Output increases from 1975 to 1990 and decreases by 2005. Only the milling and feed sector does not show an absolute decrease after 1990. This is explained by increasing feedlot activities in the study area. The most significant output changes occur in the chemicals and petroleum products sectors. For each dollar value of output, the irrigated crop production sectors spend a significant share (compared to dryland production) with these sectors. Thus, as groundwater supplies are limited and the number of irrigated acres declines the chemicals and petroleum sectors are adversely affected.

Table 1. Estimates of output, employment, and household income in response to agricultural production in the high plains of Texas and Western Oklahoma[1]

Most Responsive Nonagricultural Sectors	Output 1975	Output 1990	Output 2005	Employment 1975	Employment 1990	Employment 2005	Household Income 1975	Household Income 1990	Household Income 2005
	----- million dollars -----			----- 1,000 persons -----			----- million dollars -----		
Agricultural Services	29.1	33.6	31.6	2.04	2.35	2.21	6.92	7.99	7.25
Milling and Feeds	35.3	39.5	41.8	0.71	0.79	0.84	5.16	5.78	6.11
Chemicals	38.2	53.3	44.5	0.38	0.53	0.45	5.79	8.08	6.74
Petroleum Products	45.1	53.5	48.7	0.45	0.54	0.49	10.38	12.31	11.20
Finance	41.7	48.6	48.4	1.67	1.94	1.94	28.65	33.39	33.25
Total	392.01[2]	473.79	445.8	129.5[3]	150.6	144.19	519.43[4]	597.58	563.07
Multiplier Effect	1.26[5]	1.27	1.28	.087[6]	.087	.085			

[1]The estimates are based on total value of agricultural output of $1.48 billion, $1.72 billion, and $1.68 billion in 1975, 1990, and 2005, respectively.

[2]Total sectoral output includes only the nonagricultural production sectors.

[3]Total employment includes employment of the agricultural production sectors.

[4]Total household receipt includes receipts from the agricultural production sectors.

[5]Output multipliers are estimates of total output per one dollar of agricultural production.

[6]Employment multipliers are estimates of employment per $1000 per agricultural output.

The total output for all sectors is the total value of output response to the value of agricultural production in the corresponding year. For example, in 1975 the total value of agricultural output is estimated at $1.48 billion. The value of goods and services required to support this level of agricultural output is an estimated $392.01 million. Using the concept of an output multiplier, each dollar value of agricultural output results in total value of regional product (agricultural and non-agricultural) of $1.26. This multiplier effect is distinguished from a typical sector output multiplier in that it is a weighted average of all the agricultural production sectors. The corresponding output multipliers are given below the total non-agricultural output estimates in table 1 for the years 1975, 1990, and 2005. Slight changes in multipliers occur as total output and cropping patterns change through time.

Employment

The employment estimates in table 1 are based on sectoral response output and employment output ratios.[2] The estimated employment represents that sectoral employment necessary to produce the output required to support the agricultural production sectors. In 1975 slightly over 2.04 thousand persons are required by agricultural services to produce the goods and services demanded by the agricultural production sectors. Total employmnet reflects the employment required in all sectors (including agricultural production sectors) necessary for agricultural output to reach estimated levels. Based on the value of agricultural output in 1975, each $1,000 value of output generated total direct and indirect employment equal to .087. The corresponding employment "multiplier" effects are given below total employment in table 1. Total regional employment necessary to support agricultural production increases from 129.5 thousand in 1975 to 150.6 thousand in 1990 and decreases to 144.19 thousand in 2005. This implies that as groundwater declines an increase in unemployment or a relocation of employment out of the region results.

[2]Employment-output ratios for the input-output sectors of the High Plains have been estimated by Osborn.

Household Income

Sectoral payments to households are estimated based on sectoral response output and the households share of each dollars value of output. For example, based on the value of goods and services that agricultural services provide for the agriculture production sectors, household receipts are estimated at $6.92 million in 1975. Payment to households increased to $7.99 million in 1990 and then decreased to $7.25 million in 2005. Household receipts are projected to increase as groundwater availability is not a constraint and then decrease as groundwater levels force reductions in irrigated acres. Regional household income, as a result of agricultural production, increases almost $80.0 million from 1975 to 1990. However, from 1990 to 2005 the corresponding estimate of regional income decreases by over $30.0 million.

Concluding Remarks

There exists widespread concern in the High Plains of Northern Texas and Western Oklahoma over projection of economic exhaustion of groundwater inventories and regional impact. To address this issue a regional programming model was developed to estimate the agricultural production adjustments that may be expected under conditions of declining groundwater. The High Plains economy is a highly concentrated and intensified agricultural production region. Model application indicates that any adjustments in the agricultural production sectors can be expected to have repercussions throughout the entire regional economy.

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