ECONOMIC IMPACT OF THE DEPLETION OF THE OGALLALA AQUIFER: A CASE STUDY OF THE SOUTHERN HIGH PLAINS OF TEXAS

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ABSTRACT

Dynamic optimization and input-output models were used to estimate the impacts of depletion of the Ogallala aquifer in the Texas Southern High Plains. It was found that cropping patterns would shift toward water efficient crops and dryland production; and regional economic activity is likely to be adversely affected.

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Economic Impact of the Depletion of the Ogallala Aquifer: A Case Study of the Southern High Plains of Texas

The economy of the Southern High Plains (SHP) region of Texas (defined here as a 19-county region of the Texas High Plains) depends on the agricultural industry to sustain economic growth and development. This region has approximately 2.5 million acres of irrigated cropland drawing water from the Ogallala aquifer, a non-renewable groundwater resource (USDA, 1999). The 1997 production value of the four major field crops (cotton, wheat, corn, and grain sorghum) grown in the SHP totaled $1.1 billion, 72% or $818 million can be directly attributed to irrigated crop production. This region produces 51% of the cotton produced in Texas, 28% of Texas corn production, 22% of Texas wheat production, and 18% of Texas grain sorghum production (Texas Agricultural Statistics Service, 1998).

While cotton is the primary crop grown in the SHP region, feed grain production from irrigated corn and grain sorghum has established this region as the leading cattle feeding area in the nation. In 1997, Texas produced 25% of the fed beef in the United States, with 63% of the fed beef in Texas being marketed from feedlots in the SHP (Texas Agricultural Statistics Service, 1998). In 1997, the total cash value for cattle and calf production in Texas was estimated at $5.8 billion, with the beef industry comprising 44% of the total agricultural receipts in Texas (Texas Agricultural Statistics Service, 1998).

Irrigated agriculture in the SHP is dependent on underground water pumped from the Ogallala aquifer. The Ogallala is a major aquifer system that stretches across parts of eight Great Plains states, from South Dakota southward to Texas, with the SHP located at the extreme southern extent of the aquifer. The Ogallala is a water-bearing sand and gravel formation with varying saturated thickness across the region (Texas Water Development Board, 1997). The development of irrigation in the SHP began in the 1940s and developed rapidly. Pumpage for irrigation in the region was estimated at 4 million acre-feet in 1949, increasing to 18 million acre-feet by 1980 (High Plains Underground Water Conservation District, 1997). The heavy pumpage has outstripped natural recharge, thereby causing declining water levels, particularly in heavily irrigated areas.

The economy of the SHP is highly dependent on the agribusiness sector. Agribusiness in the SHP is composed of many interdependent components that sustain and enhance economic growth for the region. In addition to the commodity production sectors within the economy, a major element of this system is the infrastructure supporting agribusiness. This infrastructure includes grain elevators, cotton gins, cattle feedlots, farm machinery and equipment dealers, trucking firms, production input suppliers (seed, fertilizer, chemicals), meat packing plants, cotton oilseed processing plants and textile mills. The agribusiness sector contributes to the production, marketing, processing and transporting of the agricultural products produced in the region and plays a primary role in the contribution of economic value to the regional economy.

The SHP is currently facing declining water reserves and reduced irrigation well yields from depletion of the Ogallala aquifer after nearly a half century of heavy irrigation pumping demand. The effects on the number of acres under irrigation and available levels of water per acre are becoming more pronounced as the aquifer is depleted. Farmers in the region have adopted more efficient irrigation methods to adjust to the changing level of available irrigation, but will be forced to return to dryland farming with its accompanying loss in revenues as the aquifer continues to decline. Given this situation, there is substantial interest in the potential impacts resulting from the depletion of the Ogallala aquifer on the SHP economy. Therefore, the objective of this study was to evaluate the impact of changes in agricultural production in the SHP due to decreased availability of groundwater from the depletion of the Ogallala aquifer on the region's economy.

Study Region

The SHP region consists of 19 counties in the Texas High Plains. The selection of the study region was determined by the number of irrigated acres within these counties, as well as the diversity in crop production. Wheat, corn, grain sorghum and cotton are produced within the defined region. In addition, each county draws extensively from the Ogallala aquifer in order to meet irrigation water requirements.

Methods and Procedures

To estimate the economic implications of the depletion of the Ogallala aquifer for the defined study region, two analytical tools were utilized. Dynamic linear programing models were used to estimate optimal cropping patterns for the study region over a 25-year time horizon. IMPLAN, an input-output modeling program, was used to estimate the economic impacts resulting from changes in crop production within the region as the availability of irrigation water declines.

The Dynamic Optimization Model

Dynamic programming models were constructed for each county in the study region to estimate future cropping patterns, optimal groundwater use, irrigation technologies, saturated thickness, and pumping lifts. The models were a modification of Feng's dynamic programming model used to estimate irrigation technology adoption in the Texas High Plains (Segarra and Feng, 1994). Feng's model was modified to include constraints for the rate of crop and irrigation technology adjustment, percent of cotton in the crop mix, and the inclusion of a wheat enterprise. Crops included in the study were irrigated and dryland cotton, grain sorghum, wheat, and irrigated corn. Irrigation technologies considered were conventional furrow, low energy precision application (LEPA) sprinkler, and dryland farming. The models were estimated over a 25-year planning horizon.

The operating cost data used for the crops were taken from Texas Crop Enterprise Budgets for the South Plains District for the 1996 crop year (Texas Agricultural Extension Service, 1996). Commodity prices used were the average prices received by farmers for 1994-1996 as reported by the Texas Agricultural Statistics Service (Texas Agricultural Statistics Service, 1994-1996). Crop yields and initial crop acres were the average for each county for 1994-1996 as reported by the Texas Agricultural Statistics Service (Texas Agricultural Statistics Service, 1994-1996).

The per unit cost of pumping water was expressed as a function of pumping lift and well yield. Pumping lift increases as the aquifer is depleted, while well yield decreases as the saturated thickness of the aquifer decreases. Therefore, recursive hydrological equations were included in the model to describe the dynamics of aquifer depletion on pumping cost and irrigation availability (Feng, 1992; Segarra and Feng, 1994). Hydrological characteristics were specified for each county to reflect differences in the aquifer across the region.

Constraints were included within the models to allow a gradual transition in both crops and irrigation technologies due to budget constraints for producers and the time needed to adopt new technologies. These constraints allowed for annual shifts of no more than 15% between crops and 5% between irrigation technologies (the average adoption of sprinkler technology within the 19 counties over the past 10 years has been 1.6% annually).

A constraint was also included in the model that restricted the percentage of total cropland that could be in cotton production. Cotton production requires less water than most of the other crops included in the analysis, in addition to being the most profitable crop under most circumstances. Therefore, under unconstrained conditions the optimization models allocated 90% or more of the available cropland to cotton production in the majority of the counties within the study region. However, it was unrealistic to expect the study region to convert entirely to cotton production since each area of the study region possess characteristics that are unique in terms of the composition of crops grown. Therefore, a constraint was included in the model that restricted the percentage of total cropland that could be in cotton production. The three northernmost counties of the region were given a restriction of 50% of total cropland in cotton production. The central counties of the study region were restricted to75% of the total cropland to be in cotton production. While the southernmost counties were free to produce up to 90% of the available cropland in cotton. These percentages were based on the current proportions of cotton in each area which was 0% to 2.5% in the northern counties, 19% to 59% in the central counties, and 60% to 86% in the southern counties.

Nineteen crop prediction models were run for the 25-year time horizon using county specific data. The output from these models provided the percentages of total acreage allotted to each crop and irrigation system per county. These percentages were then applied to the total number of crop acres within each county to estimate the quantity of acres of each crop produced under furrow irrigation, sprinkler irrigation, or dryland conditions within the county.

The production values of these acres over the 25-year time horizon were calculated using the 1994-1996 average per acre yields and prices to match the use of the 1995 IMPLAN data base used in the input-output analysis. The calculated dollar values represented the annual agricultural production values for each crop. The use of constant prices throughout the time horizon allowed the changes in cropping patterns due to changes in irrigation capacity related to declining water availability to be the deciding factor driving economic activity.

IMPLAN

An input-output model using IMPLAN (IMpact Analysis for PLANNING) was constructed to estimate how the SHP regional economy would be affected as the saturated thickness of the Ogallala aquifer diminishes. The economic activity generated by the production of cotton, wheat, corn and grain sorghum was estimated and analyzed using

IMPLAN for the 25-year time horizon in five year increments. Olson and Lindall (1997) describe input-output analysis as involving the assessment of change in overall economic activity resulting from a corresponding change in one or several industries. Though this type of analysis does not allow for dynamic optimization, it permits the user to estimate economic impacts at a given point in time and, by combining the results of a succession of years, estimate a trend in economic activity can be discerned.

Input-output analysis is based on the assumption that interindustry transactions (production for consumption) plus final demand equals the total economic activity in an economy. Therefore, total economic activity is a function of final demand (Olson and Lindall, 1997). Industries contribute goods and services for final demand or to those activities triggered by final consumption. In calculating the effects of a change in final demand, input-output analysis provides output, income, employment and value-added impact analyses with which to quantify "shocks" to the economy.

Final demand within the cotton, feed grain (corn and grain sorghum), and food grain (wheat) sectors of the regional economy were derived using the estimated production values from cotton, grain sorghum, corn, and wheat in the study region. The model was calculated using the 1995 data set which was the most recent data set available (MIG, Inc., 1997). Estimated production values from 1996 served as a baseline because they represented the first year of optimization for the dynamic programming models. Impact analysis was conducted in five-year increments for the 25-year time horizon. The result of the analysis was six "snapshots" of the regional economy into the future.

Results

Decreasing saturated thickness of the aquifer and increasing irrigation well pumping lifts over the 25-year time horizon illustrated the dynamic nature of the Ogallala aquifer in this region. The average decrease in the saturated thickness of the aquifer over the time horizon for all counties in the region was 18.1%, while the pumping lift increased an average of 8.2% for the region. Hale, Lamb, Castro and Lubbock Counties experienced the greatest change with regard to these two variables, with the impact on water availability seen by the transition to dryland farming within these counties. As irrigation water availability decreased, the only options available to producers were to produce crops that utilized less irrigation water or to switch to dryland farming. Lubbock, Lamb, Hale and Castro counties all saw large increases in the proportion of dryland acres over the time horizon. Dryland farming increased 30.5% in Lubbock County, 32.4% in Lamb County, 45.8% in Hale County, and 46.3% in Castro County. These percentages are based on the transition from the first year of optimization to the year 2025. It can be inferred from these two measurements of water availability that the greater the change in well pumping lift and saturated thickness, the faster the movement towards dryland crops. A more detailed discussion of the transition to dryland farming and changes in aquifer characteristics can be found in Terrell, 1998.

The estimated production values for cotton, corn/grain sorghum, and wheat are given in Table 1. The baseline year of 1996 represents the initial optimal solutions for the dynamic optimization models. The optimal solutions for the baseline year are used to facilitate comparisons to other years in the time horizon. The total production values of crops increase from 1996 to 2000 because of increased cotton production as cotton is substituted for corn/grain sorghum and wheat. From the peak in 2000, the production value of crops decline by 7.5% in 2025. Cotton production value increased by 18.9% from 1996 to 2005 and then started to decline, yet the overall increase from 1996 through 2025 was 15.8%. Corn/grain sorghum production values declined throughout the period by 38% from 1996 through 2025. Wheat production value declined by 5.4% over the period.

Table 1. Production Value of Crops in the Southern High Plains Region.

Year	Cotton	Corn/Grain Sorghum	Wheat	Total
		$ Millions		
1996	1,053.3	240.6	79.5	1,373.4
2000	1,238.3	212.8	57.6	1,508.6
2005	1,252.7	193.7	59.6	1,506.0
2010	1,242.3	179.1	66.5	1,487.8
2015	1,219.7	170.7	70.2	1,460.6
2020	1,194.6	161.0	72.8	1,428.4
2025	1,169.8	149.6	75.2	1,394.5

Aggregated IMPLAN Results

Direct, indirect, induced and total economic impacts resulting from crop production value in the SHP are presented in Table 2. Direct impacts represent the production value of crop production. Indirect impacts represent the response of all industries within the region caused by industries purchasing from other industries as the dollars of crop value move through the economy. Induced impacts represent the response of all industries within the region caused by the expenditures of new household income generated by the direct and indirect effects (Minnesota IMPLAN Group, 1996). These results indicate that the region would see a decline in economic activity stemming from reduced crop production starting in 2000. Total economic impacts for the region declined by approximately $190 million from the peak value in 2000. The direct impacts of the changes in crop production value deceased 7.6% from the high in 2000. Though the economic impacts remained positive compared to the 1996 baseline, the analysis demonstrates a downturn in the economy even when farmers produce at profit-maximizing levels.

Table 2. Economic Impacts of Crop Production Values for the Southern High Plains Region.

Year	Direct	Indirect	Induced	Total
		$ Million		
1996	1,373.4	686.4	252.7	2,312.6
2000	1,508.6	757.8	281.1	2,547.5
2005	1,506.0	757.7	281.1	2,544.7
2010	1,487.8	749.3	277.6	2,514.7
2015	1,460.6	735.8	272.4	2,468.8
2020	1,428.4	720.0	266.3	2,414.7
2025	1,394.5	703.3	260.0	2,357.8

Conclusions

The results of this study support the conclusion that as the saturated thickness of the Ogallala aquifer diminishes and pumping lifts of irrigation wells increase, the regional cropping patterns will begin to shift toward more dryland agriculture. As water availability decreases, farmers will reevaluate their traditional cropping patterns. When faced with reduced water availability, the results indicate that the optimal solution for producers will be to shift their focus to those crops that utilize less water during the growing season, and to adopt the most efficient irrigation technologies.

Irrigated and dryland cotton were consistently the optimal choices. In comparing the net returns of all possible combinations of crops and technology, irrigated cotton surpasses all other crops. Although irrigated corn displayed high levels of gross returns, irrigation requirements and the associated costs of production caused its acreage to diminish within the region. The low profitability of irrigated and dryland grain sorghum and wheat caused these crops to decrease, although dryland wheat production increased in the latter years of the time horizon.

As feed grain production declines in the SHP, the cattle feedlot sector of the regional economy may experience associated impacts. In 1997, the feedlot sector contributed approximately $2.655 billion in output value to the regional economy (Texas Agricultural Statistics Service, 1998). As production from the feed grain sector declines, this may negatively affect the cattle feeding industry in this region due to the symbiotic relationship between the two sectors.

The results point to the conclusion that cotton is "king" in the SHP region and should be regarded as the crop of choice for producers. Yet, this analysis does not take into consideration the threat that boll weevil infestations present to an economy dominated by cotton production or possible changes in crop prices in the future. Recognizing these limitations, the results demonstrate important trends for the area's regional economy. Even producing at an optimal level dominated by cotton production, the contribution of agricultural production to the regional economy is reduced given a declining irrigation groundwater resource.

This analysis represents a lower bound estimate in terms of the negative economic impacts resulting from the depletion of the Ogallala because of the assumption that all farmers will produce at the optimal level, which entails the willingness to make the transition to dryland farming and more efficient irrigation technology. Additionally, the optimization models are based on the assumption that as long as there is any positive net return a farmer will continue to produce, which is not necessarily the case.

Not only will the sectors facing decreasing agricultural production be affected, but the economy as a whole will be affected due to the interdependence between all industries in an economy and the corresponding multiplier effects of any change within an economy. Once regional agricultural production peaks and begins to decline through diminished irrigated acreage, the entire economy would be affected. The direct effects from agricultural production will be reduced as dryland crops with their associated yields replace higher yielding irrigated crops. In turn, this reduction in the final demand within the agricultural sectors will ripple through the economy and effect virtually everyone within the region to some degree. This occurs through the indirect and induced effects of a change in final demand. Employment, and thus household consumption, will eventually be impacted as the regional economy dominated by agriculture begins to feel the effects of decreasing irrigated crop production.

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