Macroeconomic Impacts of Water Use in Agriculture

Justin Weinheimer
Research Associate
Department of Agricultural and Applied Economics
Texas Tech University
justin.a.weinheimer@ttu.edu

Erin Wheeler-Cook
Research Associate
Department of Agricultural and Applied Economics
Texas Tech University

Don Ethridge
Emeritus Professor
Department of Agricultural and Applied Economics
Texas Tech University

Darren Hudson
Larry Combest Endowed Chair for Agricultural Competitiveness
Department of Agricultural and Applied Economics
Texas Tech University

Selected Paper prepared for presentation at the Southern Agricultural Economics Association Annual Meeting, Orlando, FL, February 6-9, 2010

Macroeconomic forces (economic growth, interest rates, exchange rates, etc.) are known to impact individual sectors of the economy, including the agricultural sector. The direct effects on the agricultural sector are typically through variables such as commodity prices, exchange rates, interest rates, production input costs, and others. Resulting shifts in production of agricultural commodities, in turn, spill back to affect aggregate output, prices, other markets, and trade balances. Prior studies of the macroeconomic impacts in agriculture have focused on either structural changes that could occur within the dynamics of the economic system or broad characteristics within the market such as land values, consumer expenditures, and agricultural incomes (Baek and Koo, 2009; Schuh, 1974; Gardner, 1981).

When swift changes occur in the macroeconomic settings, industries and their sectors react. Within the agricultural sector, recent rapid increases and subsequent rapid decreases in commodity prices, for example, had the expected direct negative effects on farm commodity prices. But some input prices, especially those derived from petroleum, also adjusted. As input prices change, resource use changes, with renewable and nonrenewable resource use being a primary interest. While there are many resources that are currently being relied upon to sustain production agriculture in the U.S., there are few more important than irrigation water, which is a critical input to production of commodities throughout the western U.S., many of which are grown in arid or semiarid environments.

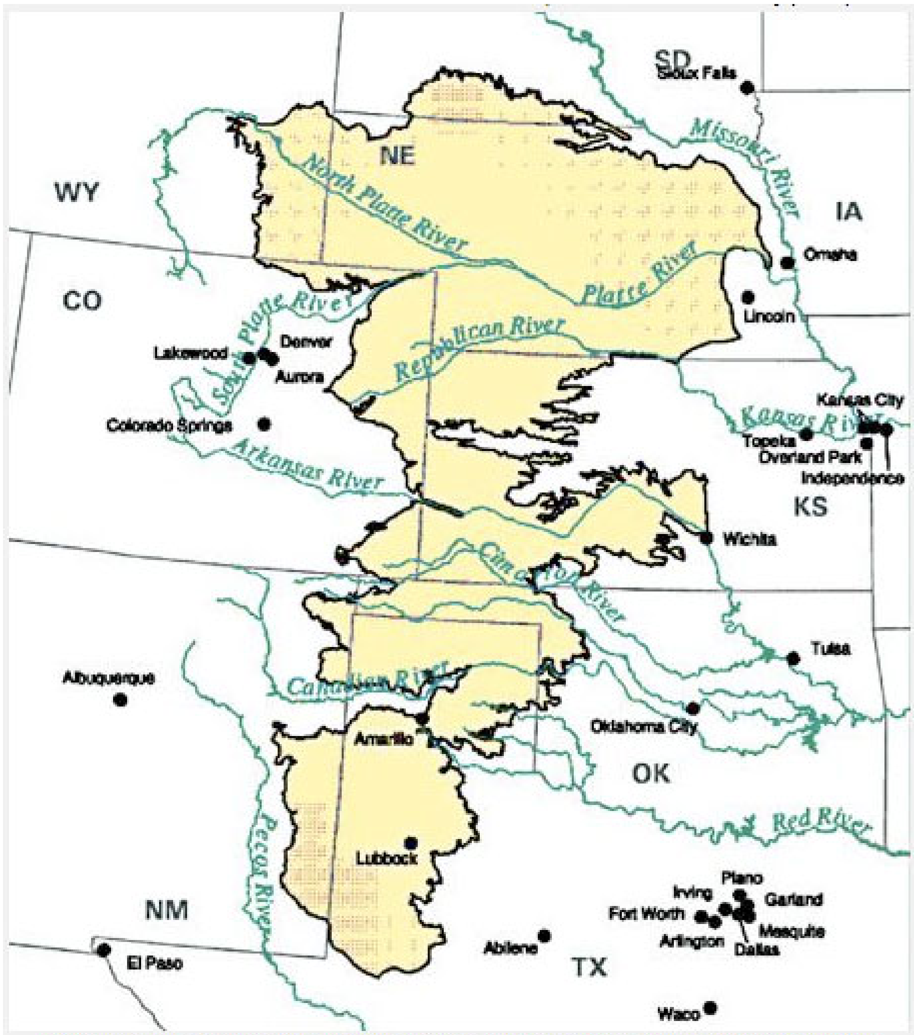
The recent/current recession that began in 2008 shifted many macroeconomic factors within the U.S. and internationally. This phenomenon provides the opportunity to study the effects of these changes on the rates of depletion of the Ogallala Aquifer and to better understand the interplay of forces within the agricultural production systems in the Great Plains of the U.S. as they impact water resource use. Therefore, the general objective of this study was to determine how the macroeconomic forces of the 2008 recession affected the rates of withdrawals (rate of depletion) from the Ogallala Aquifer in the southern Great Plains. Specific objectives were to : (1) identify representative water resource situations in the region, (2) determine the changes in farm-level prices and costs caused by the recession, (3) estimate the adjustments in water use caused by those changes, and (4) compare those results to what is estimated to have occurred had the recession not occurred.

Within the U.S., the semi-arid Great Plains (Figure 1) is a major contributor to the production of primary commodities, accounting for 51% of the wheat, 24% of the corn, 25% of the cotton, 60% of the soybeans, 50% of cattle, and almost 80% of the grain sorghum (Wishart, 2004; NASS, 2004). Rainfall across the Southern region of the Great Plains ranges from 15 to 20 inches annually. While the far west relies heavily on surface water from diverted rivers for irrigation, the Great Plains relies almost exclusively on ground water for irrigation needs. The dominant groundwater aquifer in the region is the Ogallala (along with several minor aquifers), and approximately 95% of the water pumped from the Ogallala is for irrigation (Wishart, 2004).

The Ogallala (Figure 2) is the largest freshwater aquifer in North America. Utilizing the Ogallala Aquifer for irrigation, the High Plains accounts for nearly 65% of the irrigated acreage in the U.S. (HPWD, 2009). Recharge of the aquifer is negligible relative to withdrawals, and 90% of the recharge is percolated through the soil through small playa lakes that dot the landscape from Texas to Nebraska (Alley, Riley, and Franke, 1999). Sources vary on the exact amount of recharge in the Southern portion of the Ogallala Aquifer, but many agree on a range from half an inch to several inches per year per surface acre (HPWD, 2009).

The 3.5 million irrigated acres overlying the Southern Ogallala Aquifer in Texas account for a significant proportion of the state's agricultural crop production, including 59% of the

Figure 1. The Great Plains.
Source: Center for Great Plains Studies, University of Nebraska-Lincoln.



Map shows the extent of the Ogallala Aquifer, which underlies parts of eight High Plains states. (Courtesy map)

Figure (2). The Ogallala Aquifer
Source: High Plains Underground Water Conservation District #1

cotton, 10% of the corn, 26% of the grain sorghum, 40% of the peanuts, and 46% of the wheat in the state (NASS, 2006). Within the 46 counties that overlie the Southern Ogallala Aquifer in Texas, some areas are more heavily irrigated; these areas generally have higher levels of saturated thickness of the aquifer but more rapid rates of depletion. Other areas have small amounts of irrigation, and some even show an increase in saturated thickness occurring through time. The following section explains the methods and procedures that were used to accomplish the objectives followed by a section discussing the results and interpretation of the analysis. The last section discusses the conclusions that are drawn from the study.

Methods and Procedures

The general approach for the study was to: (1) identify three counties of the Southern High Plains that represent typical water situations and cropping patterns in the region, (2) use the 10-year Food and Agricultural Policy Research Institutes (FAPRI) baseline projections for 2008 and 2009 as indicators of the macroeconomic conditions on agricultural commodity prices and input costs to represent pre-recession conditions and recession conditions, and (3) apply the Southern High Plains Ogallala Model (OM) to the situations in the three counties under the two FAPRI projections to estimate the effects on water withdrawals.

The three counties selected were Floyd, Lubbock, and Yoakum counties in the Southern High Plains region of Texas. These counties represent distinct situations, varying in climatic factors, hydrologic characteristics, soil types, and cropping patterns. Primary drivers of the crop mix allocations within each county are soil type and irrigation availability. The general county level hydrologic characteristics and enterprise allocations are represented in Tables 1 and 2. Future projections for the representative situations in the Southern High Plains used expected

Table 1. County level crop patterns.

Crop	County		
	Floyd	Lubbock	Yoakum
	----------------------------Acres--------------------------		
Irrigated Cotton	103,900	157,950	61,526
Irrigated Corn	7,925	-	-
Irrigated Sorghum	19,525	5,700	5,250
Irrigated Peanuts	-	-	21,750
Irrigated Wheat	11,650	4,225	24,450
Dry Cotton	56,275	97,300	68,900
Dry Sorghum	19,300	7,625	13,300
Dry Wheat	80,425	21,100	13,100

Table 2. County level aquifer hydrologic characteristics

Characteristic	County		
	Floyd	Lubbock	Yoakum
Avg. recharge (inches/yr)	3.7007	3.3196	2.3621
Avg. specific yield (%)[i]	0.154	0.155	0.153
Avg. saturated thickness (ft)	76	56	52
Avg. pump lift (ft)	226	130	94
Avg. well yield (gpm)	205	146	135

[i] Specific Yield is defined as the percentage of one foot of saturated thickness sands in the Ogallala Aquifer which contain water

commodity prices and production costs based on the baseline projections in the FAPRI 2008 and 2009 World Agricultural Outlooks. These prices and costs of production are based on FAPRI's outlook projections which account for many complex factors within the agricultural sector such as the general economic setting, agricultural policy, weather, and technical progress.

FAPRI's assumed macroeconomic conditions are summarized in Table 3. The world GDP growth estimates are higher for the early years (2009 and 2010) of the 2008 outlook while the 2009 baseline represents the recession conditions with a negative growth value for 2009. Projected prices for the commodities in the Southern High Plains Region were localized by estimating a basis (average 1990-2007) between the national price provided by FAPRI and Texas Southern Plains prices provided by NASS (2008). This basis was then applied to the forecasted prices for each baseline and crop within the analysis. The price for cotton includes a weighted value for the price of cottonseed based on a 1:3 turnout ratio of lint to cottonseed. The 2008 price projections reflect the outlook at the beginning of 2008. In the 2009 baseline, projected prices declined as the commodity boom slowed in conjunction with the global and U.S. economic declines.

Enterprise costs of production were obtained from Texas crop and livestock budgets produced by the Texas Agrilife Extension Service for District 2. The enterprise budgets were adjusted for each year of the ten year time horizon based on FAPRI predictions of percentage changes in input costs. Excluding electricity and labor costs, all cash field expenses were shifted based on the changes in U.S. indices of prices paid by farmers provided by the outlook. Farm program enrollments such as direct and counter-cyclical payments or crop insurance programs were not included within the revenue calculations of this analysis.

Table 3. Sample of macroeconomic projections within the FAPRI 2008 and 2009 baselines.

2008 FAPRI Baseline Projections	Year									
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Real GDP Growth Projections	(Percentage Change from Previous Year)									
World	3.3	3.6	3.5	3.5	3.3	3.2	3.2	3.2	3.3	3.2
United States	1.9	2.7	2.8	2.9	2.5	2.3	2.3	2.4	2.4	2.4
Exchange Rate* Growth Projections										
Australia	-1.6	1.6	-1.6	0.1	0.3	0.0	0.0	0.0	0.0	0.0
Canada	-6.7	2.0	1.1	1.1	0.5	2.0	2.2	1.8	1.0	-0.4
European Union-15	-9.2	2.6	3.3	2.7	2.0	0.2	-1.2	-1.4	-1.4	-1.4
Japan	-11.2	-6.0	-2.6	-1.2	-0.8	-0.4	-0.2	-0.1	0.1	0.3
Population Growth Projections										
World	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.1	1.1	1.0
United States	0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8
Petroleum Price	(Dollars per Barrel)									
Refiner Acquisition Cost of Crude Oil	80.9	76.1	69.8	69.3	68.2	67.5	67.3	67.4	67.0	67.0

2009 FAPRI Baseline Projections	Year									
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Real GDP Growth Projections	(Percentage Change from Previous Year)									
World	-0.7	2.6	3.8	3.7	3.5	3.4	3.4	3.4	3.4	3.4
United States	-2.5	2.2	3.2	2.8	2.5	2.6	2.8	2.9	3.0	3.1
Exchange Rate* Growth Projections										
Australia	18.0	-0.5	-5.9	-1.7	0.2	0.2	0.2	0.2	0.2	0.2
Canada	15.9	-8.3	-6.6	-2.0	-0.2	2.6	2.7	0.7	-1.9	-0.2
European Union ‡	9.9	0.0	-2.4	1.3	-0.7	-1.2	-1.4	-1.4	-1.4	-1.4
Japan	-10.2	0.1	-3.7	-0.9	-0.4	-0.2	-0.2	-0.1	0.0	0.0
Population Growth Projections										
World	1.2	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.1	1.1
United States	0.9	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8
Price	(Dollars per Barrel)									
Refiner Acquisition Cost of Crude Oil	31.5	47.4	71.9	80.8	86.4	86.0	80.7	79.3	79.3	79.3

* In local currency per U.S. dollar
‡ Not all European Union Members have adapted to the euro.

Originally developed by Feng and Segarra (1992), the OM is a non-linear dynamic economic optimization model that embodies hydrologic conditions (as constraints) for each county within the study area. The model effectively represents the average of production and hydrologic conditions in each county. These county level models allocate available irrigation water among enterprises so as to maximize discounted net returns per acre. Thus, 10-year projected cropping patterns and water use were obtained for each of the three counties under the 2008 baseline projections (pre-recession), and under the 2009 baseline projections (recession). The OM optimization model was estimated using the General Algebraic Modeling System (GAMS), a computer optimization program. The results indicate the optimal path for enterprise decisions under the specified conditions. The model maximizes the net present value of returns through a specified time horizon, utilizing the specified economic, agronomic, and hydrologic constraints and variables. Two separate scenarios were evaluated under the baselines. The first allowed both costs of production and prices to vary by year, according to the price and cost projections from the FAPRI projections, for the ten years of the study period. With these projections, however, it is not possible to isolate the effects of commodity price changes on water use from the effects of production cost changes on water use. Thus, the second scenario aims to isolate the price effects on water use by holding constant the costs of production at 2008 values. Comparing the two sets of water use adjustments permits the isolation of the expected effects of production cost changes driven by the recession from the expected commodity price changes driven by the recession.

The yield data utilized within the modeling process were determined through simulations conducted in CropMan (Gerik and Harman), a software program used to estimate crop characteristics based on regional climatic and environmental characteristics such as local rainfall, ambient temperatures, and soil profiles. The simulations from CropMan are county specific estimates based on variations in irrigation water applied holding other production inputs constant. The resulting yield response values to irrigation developed in CropMan were then used to estimate crop yield production functions relative to irrigation levels using Ordinary Least Squares (OLS) regression procedures.

The livestock component of the model was a dryland grazing system on mixed improved pasture, 50% WW-B-Dahl and native grasses. Contract grazing revenues were derived from gains per acre determined from Gillen (1999) and the Sustainable Agriculture Research and Education (SARE) research project at New Deal, Texas, (Allen 2005). It was assumed that the only livestock costs were the amortized costs of establishment All variable costs associated with the livestock system were assumed to be incurred by the contracted tenant (i.e., the pasture was assumed leased to a leaser who owned the livestock).

The data used to categorize the irrigation components and aquifer characteristics were obtained from the Texas Water Development Board, the High Plains Underground Water Conservation District No. 1 (HPWD) and the Texas Tech Center for Geospatial Technology (2009). Since the county models evaluated several scenarios of varying saturated thickness levels, the initial well yields for each saturated thickness level were estimated using an equation developed by Lacewell (1973)[ii] . While the exact recharge of the Ogallala Aquifer is not certain, estimated values for recharge were based on work originally developed by Stovall (2001).

[ii] Gallons per minute (GPM) based on Saturated Thickness (ST);
GPM = 2.234*ST+.0078336*ST^2-.000282*ST^3

Results

The results of this study are presented at the county level by scenario. Within each county, the first scenario allows both the prices and the costs of production to vary between the 2008 and 2009 FAPRI projections over the ten years of the time horizon. The second scenario attempts to isolate the price affects by holding production costs constant at the 2008 levels while allowing the prices to change. Then comparisons are made across counties and implications of the differences across the counties are examined. As with many modeling procedures, the results presented are compared against a baseline; in the case of this study the baseline assumed the 2008 FAPRI model projections. Changes in the FAPRI outlook were reflected in the OM model through changes in output prices and input costs resulting from the changing macroeconomic environment that occurred primarily in 2008.

Scenario I

The changes in water use when both prices and costs of production are allowed to change are presented in Table 5 for the ten year planning horizon. There were no shifts in cropping patterns in any of the counties studied during the 10-year period of this study. The results showed differences across counties in the amounts of water pumped, however. Floyd County, which has relatively more water available to pump (higher saturated thickness of the aquifer--73ft), increased pumping from the aquifer, with a cumulative increase of 3.15% over ten years. This change was the result of the lower commodity prices and the lower pumping costs, but was possible because there was sufficient water available for increased pumping to occur. In this case, a decline in the price of electricity causes the water use to increase slightly which increases

Table 5. Water use by county and year, Scenario I.

2008 Baseline (acre-feet/year)

Year	Floyd	Lubbock	Yoakum
1	236,102	267,325	127,059
2	223,024	267,325	127,059
3	221,791	267,325	127,059
4	220,859	267,325	127,059
5	220,373	263,871	127,059
6	220,938	250,391	127,059
7	221,014	238,208	127,059
8	221,035	227,162	127,059
9	220,639	217,117	127,059
10	220,426	207,957	127,059
Cumulative	2,226,202	2,474,005	1,270,590

2009 Baseline (acre-feet/year)

Year	Floyd	Lubbock	Yoakum
1	227,451	267,325	127,059
2	228,187	267,325	127,059
3	228,512	267,325	127,059
4	229,313	266,750	127,059
5	229,956	262,576	127,059
6	230,360	250,551	127,059
7	230,576	238,353	127,059
8	230,638	227,294	127,059
9	230,798	217,237	127,059
10	230,512	208,067	127,059
Cumulative	2,296,304	2,472,802	1,270,590

Cumulative Change	**3.15%**	**-0.05%**	**0.00%**

yields to compensate for the decrease in commodity prices seen in the 2009 projections. This scenario will likely be played out throughout the Southern High Plains in counties which have relatively high water available to irrigate and are currently not at maximum pumping capacities.

Lubbock and Yoakum Counties exhibited a different reaction to the U.S. recession when compared to Floyd County. These counties had little or no changes in crop water use. Cumulative water consumption in Lubbock dropped slightly (-0.05%) from the 2008 to 2009 baseline, while Yoakum showed no change. Unlike Floyd County, Lubbock and Yoakum Counties do not have the pumping capacity to increase pumping.

Thus, the model results for Scenario 1 indicate that the overall impact of the recession have likely increased water withdrawals from the Ogallala in conditions where there is sufficient water available in the aquifer to permit increased pumping. The implication is that the increased incentive to use more water due to lower pumping costs associated with the lowered energy costs from the recession outweighed the incentive to use less water due to lower commodity prices from the recession. In cases where producers were already at their pumping capacity, the recession had no impact on water use (but there may have been an impact on net returns).

Scenario II

While the results from Scenario 1 indicate how water use can be impacted from changes in the production environment through both price and input costs, it is difficult within these to isolate the primary driver behind water use changes as commodity prices and factors of production potentially move in opposite directions between the two baseline projections. To isolate the price effects alone, input costs/production costs/operating expenses were held constant at 2008 values while commodity prices were allowed to fluctuate between the baselines. The ten year results in water use for this scenario are shown in Table 6. In this scenario, Floyd County showed a slight cumulative decline (-0.47%) instead of the slight increase (3.15%) under Scenario 1. Lubbock County showed a 0.09% decrease compared to the 0.05% decrease in scenario 1 and Yoakum County had no change (0.00%) in both scenarios.

Thus, as commodity prices declined, *ceteris paribus*, producers in two out of the three counties would have responded by lowering water use, even if only slightly; this is the expected result and is consistent with theoretical expectations. As in the previous scenario, Floyd County showed the greatest change while Lubbock and Yoakum remained minimal in their reaction to the changing production environment. The lack of response in Yoakum County may be due to their water resources being committed to the point of no flexibility, at least within the range of price and cost variations represented in this analysis.

Comparing scenarios 1 and 2 also suggests that within the Southern High Plains with the groundwater situation represented in this analysis, water use is likely more responsive to variations in the cost of pumping water than to variations in commodity prices, at least within the range of changes caused by the 2008 recession. While in general (across the three counties represented in this study) the lowering of commodity prices represented by the recession caused a decline in water use and the lowering of input costs, particularly energy costs, caused an increase in water use. In this case, the latter effect was larger than the former. Comparisons across counties suggest that the nearer (farther) the water resource use is to the capacity, the less (more) flexibility in water use that will result from shifting macroeconomic factors, commodity prices, and water pumping costs.

Table 6. Water use by county and year for Scenario II.

2008 Baseline (acre-feet/year)

Year	Floyd	Lubbock	Yoakum
1	236,102	267,325	127,059
2	223,024	267,325	127,059
3	221,791	267,325	127,059
4	220,859	267,325	127,059
5	220,373	263,871	127,059
6	220,938	250,391	127,059
7	221,014	238,208	127,059
8	221,035	227,162	127,059
9	220,639	217,117	127,059
10	220,426	207,957	127,059
Cumulative	2,226,202	2,474,005	1,270,590

2009 Baseline (acre-feet/year)

Year	Floyd	Lubbock	Yoakum
1	218,495	265,332	127,059
2	219,568	265,891	127,059
3	220,092	265,595	127,059
4	221,123	265,922	127,059
5	221,951	264,770	127,059
6	222,454	251,201	127,059
7	222,787	238,941	127,059
8	222,966	227,828	127,059
9	223,233	217,724	127,059
10	223,001	208,511	127,059
Cumulative	2,215,668	2,471,715	1,270,590

Cumulative Change	**-0.47%**	**-0.09%**	**0.00%**

Summary and Conclusions

The purpose of this study was to determine how the 2008 recession impacted water use in irrigation in the Southern Great Plains. It included effects from both the decreasing commodity prices and the decreasing input costs. The basic approach was to incorporate the commodity price and input cost projections under pre- and post-recession generated by the FAPRI consortium into Southern High Plains Ogallala Model, which incorporates the groundwater hydrologic characteristics of the region. Simulation scenarios were run that (1) allowed both commodity prices and input costs to change and (2) only allowed commodity prices to change, and results were analyzed and compared.

Based on the findings of this study, the following conclusions are offered:

1. Overall, the 2008 recession likely had a relatively small impact on water use in the Southern Great Plains.
2. The crop mix in the region is relatively unresponsive to changes in the cost of pumping water and commodity price changes.[iii]
3. Water use within the region is responsive to economic forces only when increased pumping flexibility exists; when water withdrawals are already at or near capacity, macroeconomic changes and changes in pumping costs and commodity prices are not likely to change water use.
4. Water use in the region appears to be more responsive to water pumping costs than to changes in commodity prices.

Note that, as with many studies of this type, the value of the analysis is to attempt to understand how external factors impact an industry in various ways (i.e., comparing alternative scenarios to a "baseline"), rather than to "predict the future." In this context, the approach taken

[iii] Crop mix results are summarized. Detailed results are available from the authors upon request.

in this study (i.e., of linking the output of an industry projection model such as FAPRI output to a water resource model such as the Ogallala Model) may offer other potential applications. For example, this modeling approach might be used to understand how changes in agricultural and commodity policy affect water use throughout the Ogallala Aquifer.

Acknowledgments

The authors would like to acknowledge the funding sources which made this project possible. The Texas Alliance for Water Conservation and the Texas Water Development Board, Cotton Economics Research Institute at Texas Tech University, The Ogallala Initiative, and the Thornton Agricultural Finance Institute, Texas Tech University, all graciously provided support for this project. Acknowledgements are also due to Dr.'s Phillip Johnson, Chenggang Wang, and Emmett Elam for their comments and contributions on earlier drafts.

References

Allen, V.G. "Integrating cotton and Beef Production to reduce Water Withdrawal from the Ogallala Aquifer in the Southern High Plains." *Agronomy Journal* 97(2005):556-567.

Alley, W.M., T.E. Reilly, and O.L. Franke. "Sustainability of Ground-water Resources." USGS Circular 1186. U.S. Geological Survey. Denver, CO. 1999.

Baek, J., and W.W. Koo. "On the Dynamic Relationship between U.S. Farm Income and Macroeconomic Variables." *Journal of Agricultural and Applied Economics* 41,2(2009):521-528.

Clark, M.K., and Peterson, J.M. "Biofuel Boom, Aquifer Doom?" Selected Paper Presentation, American Agricultural Economics Association Meetings, Orlando FL, 2008.

Feng, Y., and E. Segarra. "Forecasting the Use of Irrigation Systems with Transition Probabilities in Texas." *Texas Journal of Agriculture and Natural Resources*, 5-1(1992): 59-66.

Food and Agricultural Policy Research Institute. FAPRI Forecast 2008: U.S. Agricultural Outlook.

Food and Agricultural Policy Research Institute. FAPRI Forecast 2009: U.S. Agricultural Outlook.

Gardner, B., "On the Power of Macroeconomic Linkages to Explain Events in U.S. Agriculture." *American Journal of Agricultural Economics* 63,5(1981):871-878.

Gerik and Harman. Crop Production and Management Model (CropMan Version 3.2). Blackland Research Center. Temple, Texas

Gillen, Robert L., Berg< William A., Dewald, Chester L., Sims, Phillip L., Sequence Grazing System on the Southern Plains. *Journal of Range Management* 52(6) Nov 1999 (583-589)

High Plains Underground Water District. "The Ogallala Aquifer" from: www.http://www.hpwd.com/the_ogallala.asp., 2009.

Lacewell, Ronald D., Pearce, John C., Model to Evaluate Alternative Irrigation Systems With and Exhaustible Water Supply, *Southern Journal of Agricultural and Applied Economics*, Dec. 1973.

National Agricultural Statistics Service. Quick Stats: Agricultural Statistics Data Base. http://www.nass.usda.gov/QuickStats.

Schuh, G.E. "The Exchange Rate and U.S. Agriculture." *American Journal of Agricultural Economics* 56,1(1974):1-13.

Stovall, J.N. Groundwater Modeling for the Southern High Plains. Ph.D. dissertation, Texas Tech University, 2001.

Texas Agrilife Extension Budgets, Extension Agricultural Economics, District 2. http://agecoext.tamu.edu/resources/crop-livestock-budgets/by-district/district-2/2008.html

Texas Tech Center for Geospatial Technology,. "Texas Ogallala Summary". http://www.gis.ttu.edu/OgallalaAquiferMaps/Default.aspx, 2009.

Texas Water Development Board. Survey of Irrigation in Texas. Report 347. August 2001.http://www.twdb.state.tx.us/publications/reports/GroundWaterReports/GWReport s/R347.pdf.

Wishart, D.J., Encyclopedia of the Great Plains. Library of Congress, 2004.

Yeboah, O., Shaik, S., and Allen A. "Exchange Rates Impacts on Agricultural Inputs Prices using VAR." *Journal of Agricultural and Applied Economics* 41,2(2009):511-520.