Economic analysis of beef cattle and groundwater

by

Sang Su Ha

M.S., University of Connecticut, 2014

M.S., Texas A&M University, 2016

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Agricultural Economics
College of Agriculture

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Abstract

As climate change progresses, extreme weather events such as floods, droughts, and abnormal high and low temperatures frequently appear. These extreme changes in weather conditions result in modifying existing production strategies throughout agriculture. Kansas' two most important agricultural sectors, beef cattle and crop production, are in need of adjusting their production strategies reflecting on climate change. This study quantifies how changing climate affects the beef carcass performance and whether adverse impacts on carcass quality can be addressed with index-based insurance. Additionally, we analyzed the possibility of an economic approach to allocating groundwater pumping rights in Western Kansas without infringement of legal ownership. Groundwater is essential for grain production in Western Kansas but has slowly been depleted. The structure of water use rights in Kansas has not been substantially altered for many years.

The first chapter examines the influence of weather stress and water quality on beef carcass yield index and marbling score. These attributes, in part, determine the market value of beef. The estimation results indicate that prolonged exposure to cold and heat stress led to deteriorated yield index and a lower marbling score. The yield index increased with longer exposures to heat or cold stress. Furthermore, the heat stress impact is larger than that of cold stress on meat productivity, and the marbling score was more vulnerable to the effect of cold stress. In order to determine how weather stresses affect profitability, we carried out a simulation analysis of beef value reduction. Simulation analysis results indicated that weather stress steadily increased producers' losses, although impaired marbling scores attributed to heat stress had a relatively limited effect on profitability. Estimation results indicate that 40 hours of exposure to heat stress corresponds to approximately a $30 loss per head. Alternatively, 40 hours of cold stress is predicted to cause a

loss of about $15 per head. Accessibility to water is essential for beef production, but the impact of water quality on beef carcass outcomes has not been researched in depth. The potential of hydrogen (pH) in groundwater slightly affected beef performance. We also confirmed no significant relationship between transportation and marbling scores was observed. Additionally, we calculated fair premium rates for a weather-index livestock insurance product that mitigates the potential and partial losses from extreme weather.

The second chapter analyzed a new groundwater permit allocation scheme for Kansas and the potential resulting groundwater savings and effects on crop production. The primary purpose of Chapter 2 was to quantify the marginal value of groundwater and assess the possibility of market-based permit trading to reduce groundwater extraction without negatively impacting the well-being of producers. The High Plains Aquifer (HPA) spreads out across eight states from South Dakota to Texas and provides more than 90% of irrigation water used in that region. Ninety-seven percent of groundwater extraction from HPA has been used for irrigation, and 76.5% of farms rely on groundwater in Kansas (USDA-NRCS 2013). Despite improvements in groundwater management in Kansas, the major problem of groundwater depletion continues. As awareness of the limitations of centralized governance approaches based on pumping restrictions has increased, localized and decentralized market-based approaches have gained popularity.

Data were collected through the use of the Water Information Management and Analysis System (WIMAS) in Kansas. We used local crop-water production functions based on Crop Water Allocator (CWA) developed by the Kansas State University Research and Extension (KSRE). We calculated the marginal value of each irrigation well using crop-water functions. These values are used to set the permit transaction price. Kansas groundwater is worth an average of $782.73 per acre-foot. The area with the highest value is Groundwater Management District (GMD) 4 at $902;

the area with the lowest groundwater value is GMD3 at $727.

Our simulations found increased farm household income in all regions with permit trading. A Uniform Double Auction generates an average income of $10,772 for groundwater sellers, and buyers may earn $13,046 after groundwater sellers have received their payment. From a regional perspective, the GMD3 region had the highest average buyer income of $15,267 and the highest average seller income of $13,840. In Discriminatory Double Auction, Sellers earned an average of $13,529 from groundwater permit sales, while buyers earned an average additional income of $10,499. However, the ultimate goal of actual groundwater use reduction through water trading is not easily accomplished due to many (65%) unused authorized quantities in Kansas. The benefit from permit trading must outweigh the economic motivation for groundwater saving. The market-based approach could promote sustainable groundwater use under the current Kansas groundwater use trend, providing more returns to farmers with higher yields. Based on these calculated values, the market-based approach increased the private net benefit, as sellers and buyers of permits are better off after trading. To make permit trading successful in Kansas with groundwater use saving, one must overcome barriers such as issuing new water permits each year, high non-use rates, and non-infringement on those who received water rights before 1964. The Kansas State Government and farmers should begin discussions and administrative support to pursue a sustainable agricultural economy due to the conservation for future generations and groundwater resources.

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Chapter 1

Introduction

Climate change refers to long-term changes in weather patterns and temperatures. These shifts commonly occur when the solar cycle changes (Raspopove et al., 2008). Human activities (i.e., burning fossil fuels such as coal, oil, and gas) also contribute to climate change (Garasso, 2019). Climate change is associated with weather events that significantly impact different sectors of society. For example, food production can be negatively affected by drought or elevated temperatures. A flood may spread disease and damage ecosystems and infrastructure.

The effects of climate change on farms include reducing crop yields, lowering the nutritional value of major market grains, and reducing livestock production (Nelson, 2009). Climate change has resulted in a 21% reduction in global farming productivity since the 1960s (Ortiz-Bobea et al., 2021). In order to meet the demand for food and to maintain current yields, substantial continuous investigation and investments may be required in adaptation (Steenwerth et al., 2014). According to Thornton et al. (2021), which examined the potential economic costs of heat stress in the future, global livestock farmers could experience losses between $15 and $40 billion annually by the end of this century. Water availability is likely to decrease with a changing climate, but demand may increase (Dettinger et al., 2015). Soils would continuously become drier as warmer temperatures increase evaporation and plant water consumption (Perry et al., 2009).

The climate in Kansas is also changed (Feddema et al., 2008; Howard et al., 2016; Araya et al., 2017). The agricultural industry in Kansas has also been adversely affected by climate change. These extreme changes in weather conditions involve modifying existing production strategies to adapt to climate change throughout agriculture. The two most important agricultural sectors in Kansas, beef cattle and crop production, may need to adjust their production strategies due to climate change.

This dissertation is focused on determining whether climate change affects the market value of beef cattle and whether this analysis can be addressed with index-based insurance. Additionally, I analyzed the possibility of an economic approach to saving groundwater, which is essential for grain production in Western Kansas, but the quantity of groundwater availability has slowly been depleted without infringement of legal ownership. This dissertation is a collection of two essays related to critical economic issues with climate change in the Kansas agricultural industry. Essay 1, "The influences of extreme weather stress and water quality on beef carcass performance", examines the influence of weather stress and water quality on beef carcass yield index and marbling score. These attributes, in part, determine the market value of a beef carcass. The estimation results indicate that prolonged exposure to cold and heat stress led to deteriorated yield index and a lower marbling score. The yield index increased with longer exposures to heat or cold stress. Furthermore, the heat stress impact is larger than that of cold stress. In order to determine how weather stresses affect profitability, we carried out a simulation analysis. Simulation analysis results indicated that weather stress steadily increased producers' losses, although impaired marbling scores attributed to heat stress had a relatively limited effect on profitability. Estimation results indicate that 40 hours of exposure to heat stress corresponds to approximately a $30 loss per head. Alternatively, 40 hours of cold stress is predicted to cause a loss of about $15 per head. Accessibility to water is essential for beef production, but the impact of water quality on beef carcass outcomes has not been researched in depth. The potential of hydrogen (pH) in groundwater slightly affected beef performance. Additionally, we calculated fair premium rates for a weather-index livestock insurance product that mitigates the potential and partial losses from extreme weather.

Essay 2, "Groundwater Permit Trading and Potential Groundwater Saving in Kansas ", analyzed potential groundwater savings as well as limitations of the groundwater permit trading using Kansas groundwater regulation and actual groundwater usage and crop production. The primary purpose of this chapter was to quantify the marginal value of wells and assess the possibility of permit trading to reduce groundwater extraction without negatively impacting the economy. The High Plains Aquifer (HPA) spreads across eight states from Texas to South Dakota and provides more than 90% of irrigation water. Ninety-seven percent of groundwater extraction from HPA has been used for irrigation, and 76.5% of farms rely on groundwater in Kansas (USDA-NRCS 2013). Despite improvements in groundwater management in Kansas, the major problem of groundwater depletion continues. As awareness of the limitations of centralized governance approaches based on pumping restrictions has grown, localized and decentralized market-based approaches have gained popularity. Data were collected using Kansas's Water Information Management and Analysis System (WIMAS). We used local crop-water production functions based on Crop Water Allocator (CWA) developed by the Kansas State University Research and Extension (KSRE). We calculated the groundwater value of each irrigation well from the crop-water functions, and these values will be the permit transaction price. Kansas groundwater is worth an average of $782.73 per acre-foot. The area with the highest value is GMD4 at $902, and the area with the lowest groundwater value is GMD3 at $727.

Our simulations found increased farm household income in all regions because of more groundwater use by permit trading. A Uniform Double Auction generates an average income of $10,772 for groundwater sellers, and buyers may earn $13,046 after groundwater sellers have received their payment. From a regional perspective, the GMD3 region had the highest average buyer income of $15,267 and the highest average seller income of $13,840. In Discriminatory Double Auction, Sellers earned an average of $13,529 from groundwater permit sales, while buyers earned an average additional income of $10,499. However, the ultimate goal of actual groundwater use reduction through water trading is not easily accomplished due to many unused authorized quantities (65%) in Kansas. For permit trading to be successful in Kansas, it must overcome barriers such as issuing new water permits each year, high non-use rates, and non-infringement on those who received water rights before 1964.

Chapter 2

The Influences of Weather Stress and Water Quality on Beef Carcass Performance

2.1Introduction

The optimal temperature for the healthy growth of beef cattle ranges from 32 degrees to 77 degrees Fahrenheit in the thermal neutral zone (Hahn, 2001). Cattle face reduced performance, lower reproductivity, and higher death and morbidity rates outside this temperature range. Cattle face reduced performance, lower reproductivity, higher death rates, and higher morbidity rates outside this temperature range. Climate scientists have predicted that temperatures will continue to rise and fluctuate more severely in the future, leading to more extreme weather events (Masson-Delmotte et al., 2021).

Extreme weather can adversely impact beef cattle production and increase the cost of cattle operations, feedlots, and processors (Demircan et al., 2007; Scholtz et al., 2013). Cattle producers may need to buy extra feed during cold weather to meet their livestock's increased energy requirements. Hot weather is also challenging as cattle cannot sweat effectively and rely on respiration to keep cool in hot weather. Cattle accumulate heat during the day and dissipate it at night when they are more relaxed because they do not dissipate heat effectively (Gaughan et al., 2008). As the number of weather-related risks increases, beef producers must take more precautionary measures to mitigate these risks.

Numerous studies have examined how heat or cold stress affects cattle biorhythm and the damaging effects of heat and cold on productivity and wellbeing. Beef cattle respond to heat stress by consuming more water and less dry matter (Hahn, 1985; Collier et al., 2006; Bernabucci et al., 2009; O'Brien et al., 2010). Studies show cold stress leads to reduced feed-to-grain ratios and weight gain in beef cattle (Mader & Davis, 2004). There are several documented periods where beef cattle producers faced serious losses due to extreme weather. For example, during the summer of 1995 and 1999, producers of beef cattle suffered a considerable loss in beef production due to heat waves (Hahn et al., 2001), severe winter storms (Mader & Davis, 2004) in Southern California, and the Midwest USA (Elam, 1971; Birkelo, 1991), as well as in several regions of Canada (Webster et al., 1970; Hidiroglou & Lessard; 1971; Milligan & Chrisfision 1974), and exceptional drought in the Southern High Plains in 2010 (Strom, 2013).

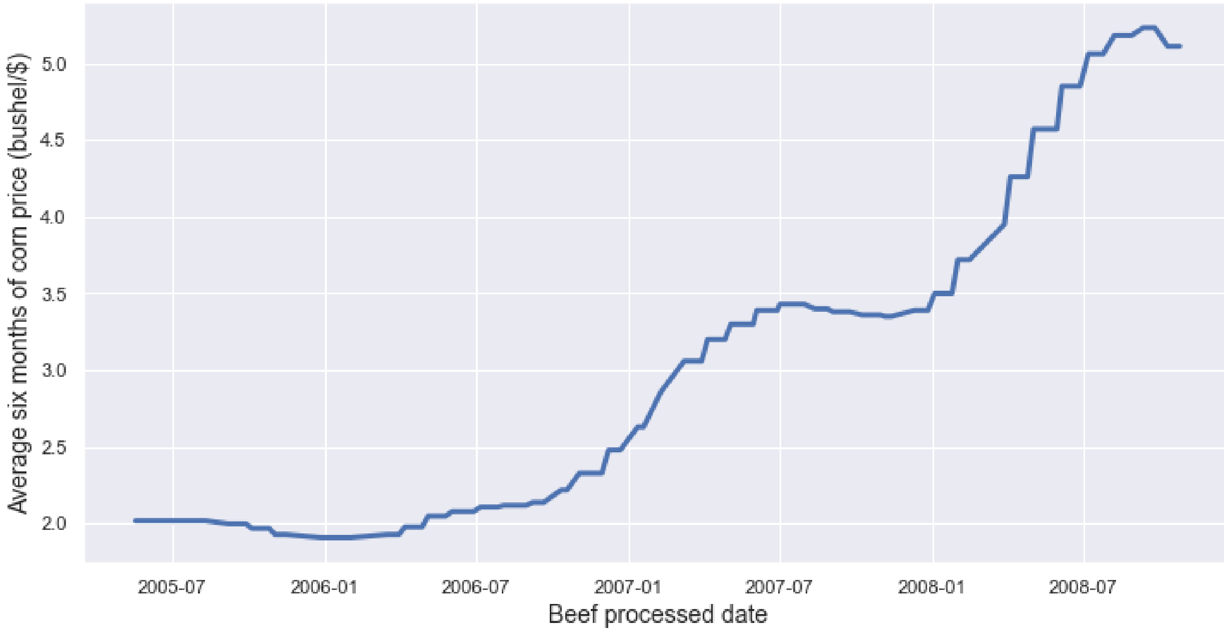
Since yield grade and marbling score are essential determinants of market value, many studies have examined the relationship between weather stresses and these factors. Weather stress and beef carcass performance generally correlate negatively. There are still slight differences in the degree of detail and the effects of treatments due to research conditions and data sources. Piao & Baik (2015) reported that cold weather conditions worsened the yield index but did not impact the marbling score. However, when temperatures go lower than freezing, beef cattle being fed for slaughter may lessen feeding intake (Abraham et al., 1980). Mader et al. (1997) and Mader and Davis (2004) found that marbling in beef ribeye muscle could increase when cattle are prepared for and adapted to cold stress. Shading and water sprinkling are two common heat stress mitigation strategies for feedlots. Mitlöhner et al. (2001) found no difference between shaded and unshaded beef cattle in marbling scores, yield grades, or quality grades. Clarke and Kelly (1996) showed that providing shade to reduce heat stress in summer had no significant effect on marbling scores. Mader and Davis (2004) found that water sprinkling in summer increased marbling scores. Given these varied findings, this study explored the effect of heat and cold stress separately on yield grade and marbling score.

Though numerous studies have explored the effects of weather stress on beef cattle production, few studies have been conducted to identify the expected losses to producers and provide them with methods to manage weather-related risks. Historically, insurance instruments were initially indemnity-based, which paid out if yields did not meet a specified percentage of those expected. However, this kind of product outcome based-insurance suffers from many issues such as moral hazard, adverse selection, and high monitoring costs (Hazell, 1992; Hess, 2007; Clarke, 2016). In response to these problems, weather index insurance is an excellent alternative to avoid some shortcomings of product outcome-based insurance (Clarke, 2016). The payout is based on an unbiased index, so farmers and insurers cannot influence the indemnity. Further, no field assessments are necessary (Clarke, 2016). Index-based insurance can minimize potential adverse selection, moral hazards, and monitoring costs (Barnett et al., 2008; Clarke, 2016). Due to these benefits, weather index insurance products are gaining popularity in the grain insurance market. Even though the United States has a well-established agriculture insurance system and over 180,000 weather stations, livestock insurance based on weather indexes is not usually available (Belasco et al., 2015). Since the weather index insurance could offset a specific risk, it could uniquely provide partial protection for beef cattle production against weather risks. Belasco et al. (2015) studied the weather stress impact on feedlot performance, including average daily gain, feed conversion, and mortality rate. They showed the possibility of weather index insurance in the live cattle insurance market Building on this premise, our study develops an objective index of beef cattle weather stress and examines its relationship with expected losses due to decreased carcass performance.

In addition to weather variables, we consider several factors measured during the time period cattle are on the feed, such as water quality, corn price, and transport stress. These could affect beef carcass performance. Water is essential for cattle's physiological and biochemical processes (Legrand et al., 2011), and water intake is sensitive to weather conditions. Cattle need double the amount of water when the temperature is 90°F compared to 40°F (Winchester & Morris, 1956). Water quality is also as important as the amount of water consumed. Most minerals by water intake support the growth of the cattle, but some minerals in water can harm the animal's health and performance if consumed in excess. For example, when a considerable amount of nitrates is ingested, they are transformed into nitrite, a highly poisonous substance to cattle, in the rumen (Stoltenow & Lardy, 2008). Nitrates (NO_3) which has an effect on water quality comes from fertilizer and manure. Nitrates are reported as a combination of nitrate and nitrite-nitrogen $(NO_3 - N)$ since nitrite is unstable and converts to nitrates before analysis (Aydin, 2013). It reduces the cattle's appetite (Cash et al., 2002). Nitrates are safe up to a concentration of 443 ppm but unsafe beyond that level (Bagley et al., 1997). Nitrate poisoning can occur if the level exceeds 1300 parts per million, which is interpreted as dangerous (Bagley et al., 1997). As a result, the hemoglobin in the blood is rendered incapable of carrying oxygen. A pH value describes how acidic or alkaline water is. The safe pH range for beef cattle's drinking water is between 6.0 and 8.5 (NASEM, 2016). Alkaline water can generate laxative effects, while acidic water may decrease feed intake (NASEM, 2016). Total dissolvable salts (TDS) indicate salinity. Salt toxicity and dehydration cause less feed intake. Ideally, the concentration of TDS should range from 0 to 1000 ppm, while anything over 4,000 ppm should be considered abnormal (Cadena, 1978). Turbidity means the degree of muddiness in water. When their water was impure, animals often reduced their intake (Carson, 2000). Heifers receiving clean water gained 23% more weight than those receiving dirty water (Willams et al., 2002). Based on the close relationship between outdoor temperature and water intake, the impact of water quality on beef production could be more severe when during periods of extreme heat.

Corn traditionally comprises a large portion of cattle feeding costs (Anderson & Trapp, 2000), and corn price is understood to have a major impact on returns (McDonald and Schroeder (2003)). As such, there have been numerous studies concerning the relationship of corn prices with weight-gain gains and producers' profitability (Albright et al., 1994; Mark et al., 2000; McDonald & Schroeder, 2003; Kaknaroglu et al., 2005; Tatum et al., 2012; Tang et al., 2017). However, few studies have examined the relationship of corn prices with marbling scores and yield index (Pyatt et al., 2005). Corn prices rose dramatically between Jan 2005 and August 2008, the time period considered in this study (Figure 2.1). As part of this study on the weather stress and beef carcasses, corn price was used as a variable. The rationale is that a lower corn price lessens the cost of adding pounds to cattle. As cattle gain weight on an energy-rich diet, marbling scores and quality grades tend to improve.

Figure 2.1. Six-month Moving Average of Corn Price from May 2005 to October 2008



Source: The figure is based on the author’s calculations using six states of corn prices from the USDA AMS.

In addition to climate stress, transport stress is a significant stressor that worsens beef cattle performance. Many studies (Eldridge & Winfield, 1988; Tarrant et al., 1992; Coffey et al., 2001; Cernicchiaro et al., 2012; Deng et al., 2017; Birhanu, 2020) provided evidence of a decrease in carcass weight and a risk of injury during transportation. Deng et al. (2017) measured the change in Cortisol, a stress hormone, secretion using the real-time Polymerase Chain Reaction (PCR) test for transportation stress of beef cattle. Beef cattle's cortisol levels increased by 32% after 6 hours, to 81% after 24 hours, and returned to their average levels only after 15 days, after an average of 14 hours of transportation. Further, recent studies also found that transportation stress can change the secretion of pituitary hormones, causing altered metabolism, immune competence, behavioral changes, and difficulty reproducing (Mitchell & Kettlewell, 2008; Goldhawk et al., 2014; Damtew et al., 2018). The impact of transport stress on beef carcass performance, including yield index and marbling score, has received little attention despite the existing studies referenced. In this study, we looked at travel time effects between a feedlot and a meat processing facility on yield index and marbling score. The travel time as total minutes was used as a proxy for transport stress instead of distance. Estimated travel time was chosen for livestock welfare; travel duration is more important to livestock welfare than absolute distance (Schwartzkopf-Genswein, 2005).

This study examined how weather stress impacts marbling score and yield index using data collected from a Midwest plant from May 2005 to October 2008. We calculate the expected losses and premium rates associated with possible weather index livestock insurance that mitigates damages from extreme weather events based on initial estimates. Our study differs from a recent study of weather insurance based on live weight gain in the feedlot (Belasco et al., 2015). We divided weather stress into hot and cold conditions and examined the relationship between weather stress and beef carcass performance, using the marbling score and yield index. We also included the price of corn and water quality in our analysis since both are related to beef carcass performance.

2.2 Data

Beef carcass data were collected from a large-scale Midwest meat processing plant. Table 1.1 shows the marbling score, yield grade, fat thickness, percentage of Kidney, Pelvic, and Heart Fat (KPH), hot carcass weight (HCW), and 12^{th} ribeye area of an individual beef carcass (16,700 heads) from May 2005 to October 2008. Camera-based grading systems were used to assess the marbling scores for each carcass.

Table 2.1. Summary Statistics for Variables (N = 16,700), May 2005- October 2008

	Mean	Std. Dev.	Min	Max
Yield Index[1]	3.17	0.73	0.26	6.34
Marbling Score	5.05	1.01	1.50	10.60
Fat Thickness (Inches)	0.51	0.16	0	1.40
KPH (Percent)	1.98	0.18	1.00	3.00
Hot Carcass Weight (Pounds)	776.51	84.67	339	1102
12^{th} Ribeye Area (Square Inches)	12.45	1.63	7.03	22.4
Hours_Heat stress[2*]	428.41	454.90	4.00	1,870.00
Hours_Cold Stress[*]	1,990.19	758.23	19.00	2,870.00
Corn Price ($/bushel, 6-Month Average)	2.90	0.96	1.91	5.23
Minutes to Packing Plant	233.16	74.42	40.00	584.00
Arsenic	1.59	2.31	0	12
NO_3	106.29	148.02	0	343
pH	7.41	0.21	6.7	8.8
Total Dissolved Solid	635.58	510.38	156	4350
Turbidity	3.62	3.86	0	35

After eliminating the head, hide, internal organs, and intestinal tract, fat thickness is measured in inches, HCW in pounds, and ribeye area in square inches. As estimated by USDA, Yield grade indicates how much edible meat is available from a beef carcass. The formula for calculating the grade (Holland & Dwight, 2013) is:

(1) Yield grade = 2.5 + 2.5 fat thickness + 0.2 KPH + 0.0038 HCW – 0.32 ribeye area.

s[1] Beef Carcass Data were collected by a Midwest meat processing plant.
[2] * The number of hours overreaching the weather stress (heat stress: CCI > 25; cold stress: CCI < 0).

From equation (1), it is apparent that fat thickness and ribeye area are major determinants of yield grade. When the external fat covering the outside of the 12th ribeye becomes thinner, and the ribeye area at the 12th rib becomes more expansive, the yield grade of a carcass becomes smaller, indicating a better market value. USDA yield grade is divided into five levels, ranging from 1 to 5. The best grade is 1, and the worst grade is 5. Marbling score provides an estimate of the quality of beef from a carcass. A higher marbling score indicates more edible fat interspersed in the muscle, which provides better flavor and tenderness. In this study, we used the marbling score and yield grade as proxies for carcass performance. As shown in Figure 2.2, most beef carcasses are classified as Choice (69.7%) or Select (28.0%) as well as Yield Grade 2 (33%) and Yield Grade 3 (53.9%). The distribution of our data is similar to the National Summary of Meat Graded (Table 1.2).

Table 2.2. National Summary of Meat Grading from May 2005 to October 2008 (million pounds, total graded percentage in parentheses)

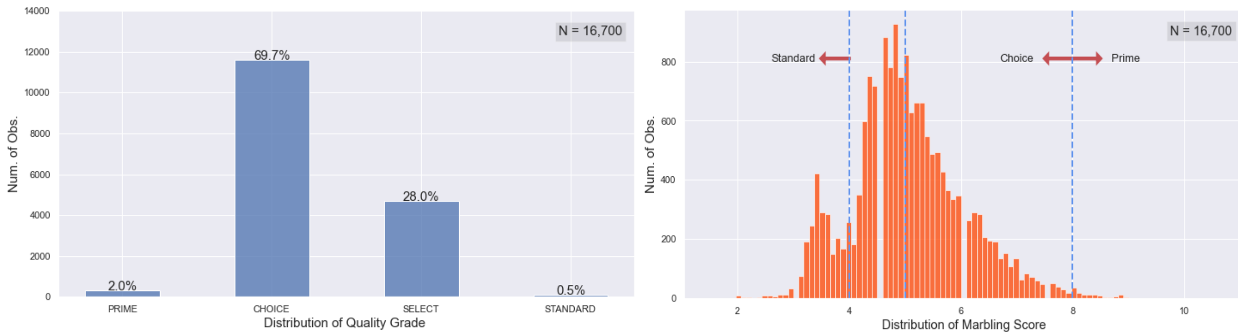
	2005		2006		2007		2008	
Quality Grade								
Prime	602	(3.1)	577	(2.9)	525	(2.6)	595	(2.9)
Choice	11,133	(57.3)	11,367	(56.2)	11,655	(58.0)	12,459	(61.0)
Select	7,679	(39.5)	8,279	(40.9)	7,872	(39.1)	7,312	(35.8)
Standard	29	(0.1)	6	(0.0)	56	(0.3)	70	(0.3)
Total	19,443	(100.0)	20,229	(100.0)	20,108	(100.0)	20,436	(100.0)
Yield Grade								
YG1	2,046	(10.6)	1,800	(8.9)	1,758	(8.8)	1,634	(9.2)
YG2	7,843	(40.5)	7,525	(37.3)	7,373	(36.9)	6,688	(37.6)
YG3	7,735	(39.9)	8,488	(42.1)	8,679	(43.4)	7,575	(42.6)
YG4	1,556	(8.0)	2,040	(10.1)	1,909	(9.5)	1,643	(9.2)
YG5	199	(1.0)	314	(1.6)	280	(1.4)	246	(1.4)
Total	19,379	(100.0)	20,167	(100.0)	19,999	(100.0)	17,786	(100.0)

Percent in parenthesis.

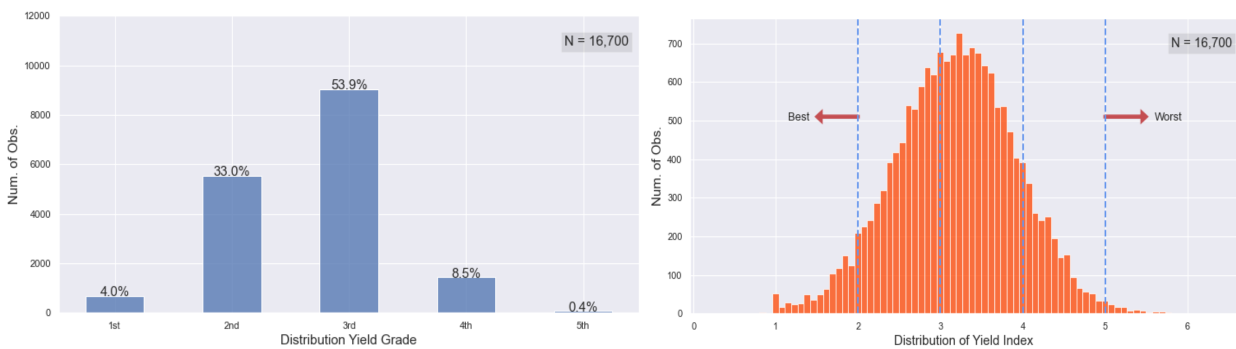
Data Source: USDA Agricultural Marketing Service

Figure 2.2. The Distributions on Quality Grade, Marbling Score, Yield Grade, and Yield Index

A. The Distributions on Quality Grades and Marbling Score



B. The Distribution on Yield Grades and Yield Index

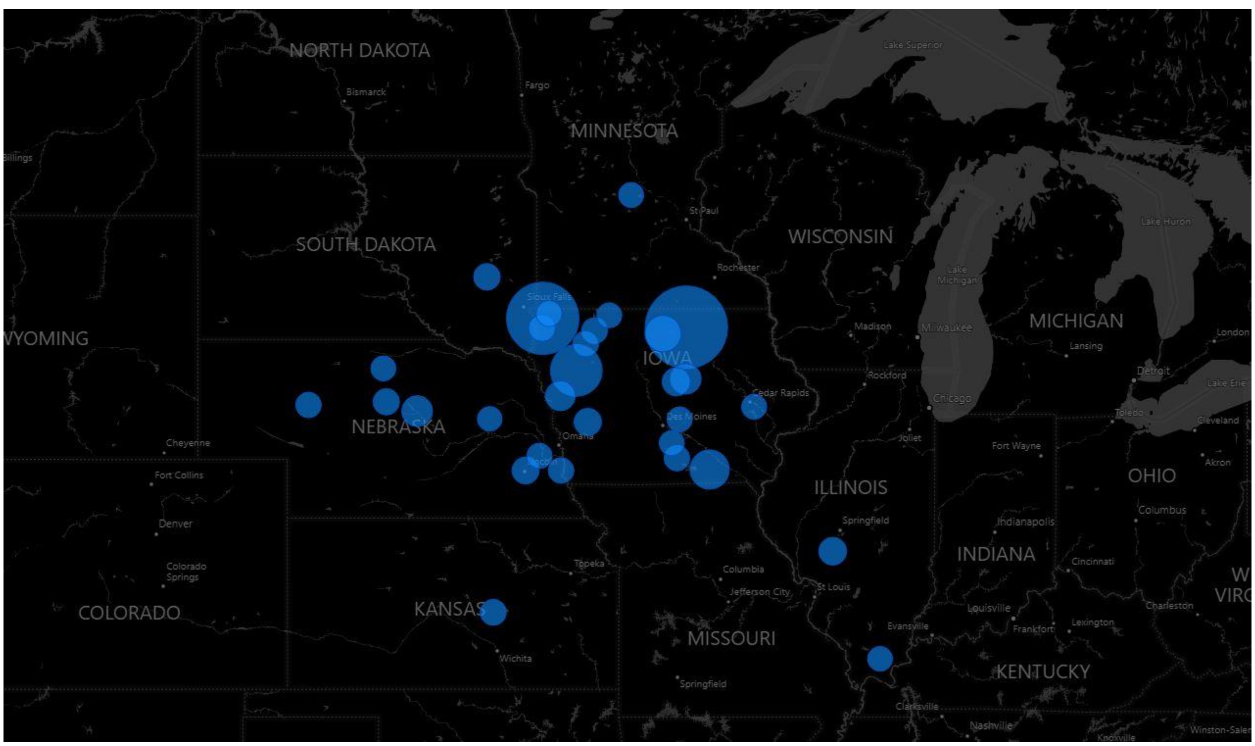


Source: The figure is the author's calculations from midwest plant carcass data.

The National Renewable Energy Laboratory (NREL) cataloged historical and geographic climate data. These data include hourly ambient temperature, relative humidity, wind speed, and solar radiation. We combined climate and beef carcass data by taking the feedlot site and the processing date into consideration. We collected corn price data from the United States Department of Agriculture Economic Research Service (ERS) as state-level data for each feedlot. Additionally, water quality data (i.e., arsenic, salinity, nitrates, and nitrites) were obtained from the National Water Information System (NWIS) of the U.S. Geological Survey.

Cattle are fed a balanced diet of roughage and grains. Cattle in feedlots are usually kept on feed for about four to six months before being sent to a meat processing plant. Then, cattle are sent to a packing plant when they reach a market weight of approximately 1,200 to 1,400 pounds. This usually occurs between 18 and 22 months old. For this reason, six-month averages of corn prices before processing dates of individual cattle carcasses were calculated and are being used to quantify how their variations impact quality and yield. We also used weather data to estimate the number of hours cattle were exposed to heat and cold stress for the preceding six months when they were processed as a proxy for weather stresses. Beef cattle on which this study is based were transported from approximately 31 counties across six states, including Iowa, Nebraska, Kansas, Illinois, Minnesota, and South Dakota (Figure 2.3; Appendix A.1).

Figure 2.3. The Regional Distribution of Cattle Feedlots



Source: The figure is the author’s work from a midwest plant carcass data, N=16,700.

The marbling degree and physiological maturity are used to calculate the USDA quality grades. Since 97% of beef cattle are harvested before 30 months of age (Garcia et al., 2008), the marbling score is the most critical factor determining the grade of the meat. The USDA quality grade represents the palatability of meat segregated into six grades (Prime, Choice, Select, Standard, Commercial, and Utility). When the marbling score of the beef carcass exceeds 8.0, it is considered Prime, the highest grade. Therefore, higher marbling scores result in better USDA quality grades.

As a measure of weather-related stress in beef cattle, a Comprehensive Climate Index (CCI) suggested by Mader et al. (2010) was used, and it can also be interpreted as a cattle comfort index. Comfortable cattle are more productive, gain more weight, and are healthier. In order to calculate CCI, we used ambient temperature (AT), relative humidity (RH), wind speed (WS), and solar radiation (SR), as suggested by Mader et al. (2010).

$$(2)\ \mathrm{CCI} = \mathrm{AT} + \mathrm{RH}^{C} + \mathrm{WS}^{C} + \mathrm{SR}^{C},$$

The correction factors of CCI are RHc, WSc, and SRc, respectively, concerning relative humidity (RH), wind speed (WS), and solar radiation (SR).

$$(3)\ \mathrm{RH}^{C} = e^{0.00182\times \mathrm{RH}+(1.8\times 10^{-5})} \times [0.000054 \times \mathrm{AT}^{2} + 0.00192 \times \mathrm{AT} - 0.0246] \times [\mathrm{RH} - 30],$$

$$(4)\ \mathrm{WS}^{C} = \left[\frac{-6.56}{e^{\left\{\left[\frac{1}{(2.26\times WS+0.23)^{0.45}}\right]\times[2.9+1.14\times 10^{-6}\times WS^{2.5}-log_{0.3}(2.26\times WS+0.33)^{2}\right\}}}\right] - 0.00566 \times WS^{2} + 3.33,$$

(5) $SR^C = 0.0076 \times SR - 0.00002 \times SR \times AT + 0.00005 \times AT^2 \times \sqrt{SR} + 0.1 \times AT - 2,$

AT, WS, and SR are measured in Celsius, meters/second, and watts/meter, respectively. Weather variables influence how well and comfortable animals are based on the correction factors. The animals are exposed to cold stress if the index is below 0 and to heat stress if CCI is over 25 (Table 1.3).

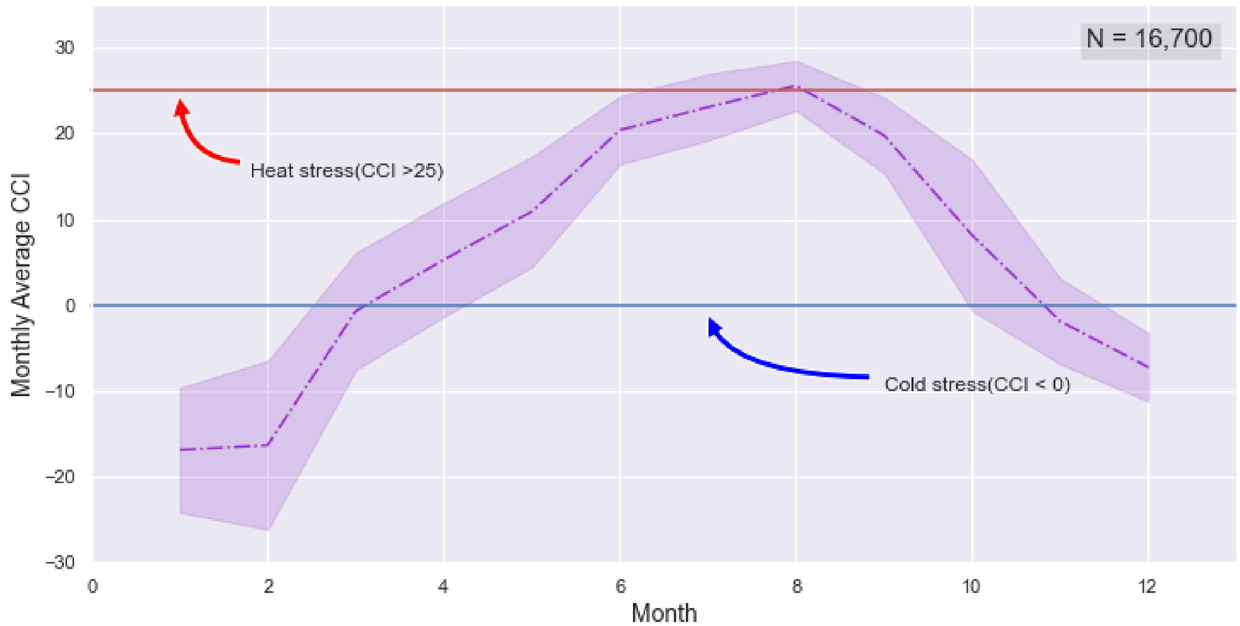
Table 2.3. The Degree of Weather Stress

Heat Stress		Cold Stress	
CCI ≤ 25	No stress	CCI > 0	No stress
25 < CCI ≤ 30	Mild	0 < CCI ≤ -10	Mild
30 < CCI ≤ 35	Moderate	-10 < CCI ≤ -20	Moderate
CCI > 35	Severe	CCI < -20	Severe

Source: Mader et al. (2010)

Figure 2.4 illustrates that the comprehensive climate index for spring and summer increased and declined from fall through winter. It can be seen in Figure 2.4 that beef cattle slaughtered between March and May were primarily exposed to cold stress, while cattle slaughtered between September and November were primarily exposed to heat stress. It makes sense to examine the impact of heat and cold stress separately on beef cattle performance since they are subject to different weather stress exposure patterns. Our sample of 16,700 beef cattle consisted of 88.0% processed during spring (March to May) and summer (June to August) when seasonal beef consumption is strong. In this study, beef cattle were exposed to more cold than heat stress.

Figure 2.4. The average Comprehensive Climate Index for processed beef cattle from May 2005 to October 2008

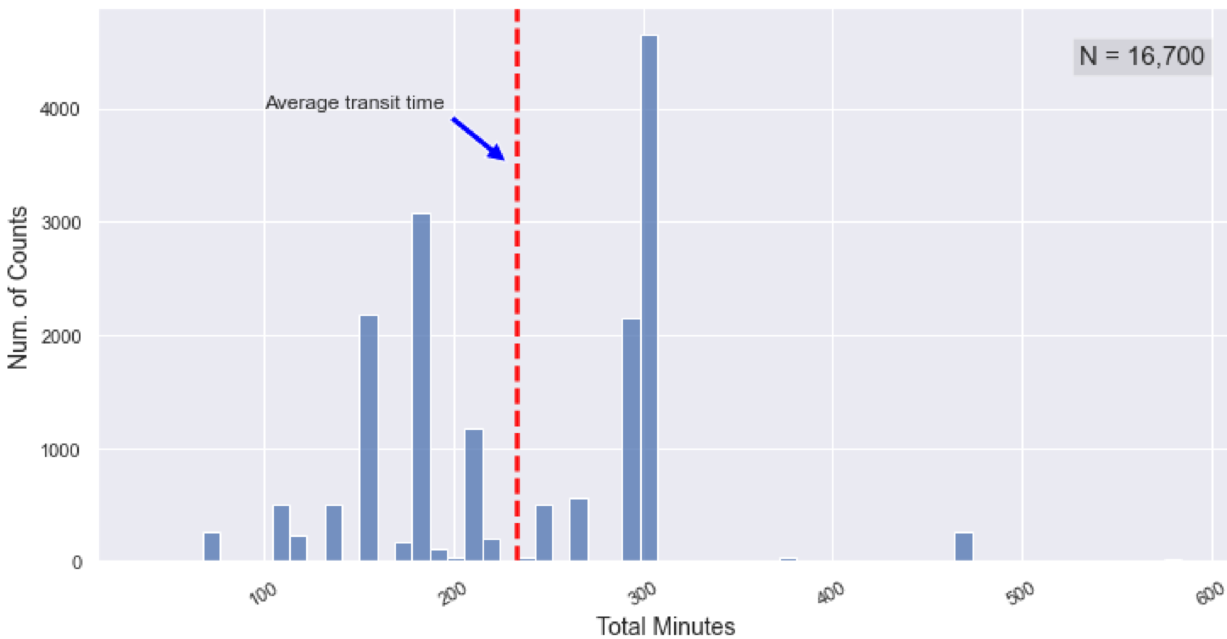


* Hours that exceed the point weather stress (Heat stress: CCI > 25; Cold stress: CCI < 0).

Source: The figure is based on the author's calculation using county-level weather data from NREL.

We can estimate the travel time with Google Maps since we know where each feedlot is located (Figure 2.5). Google's travel time is calculated by estimating an average travel speed using marked speed limits and historical traffic patterns. As explained earlier, total travel time corresponds to animal welfare (Schwartzkopf-Genswein, 2005).

Figure 2.5. Travel Minutes to Meat Processing Plant

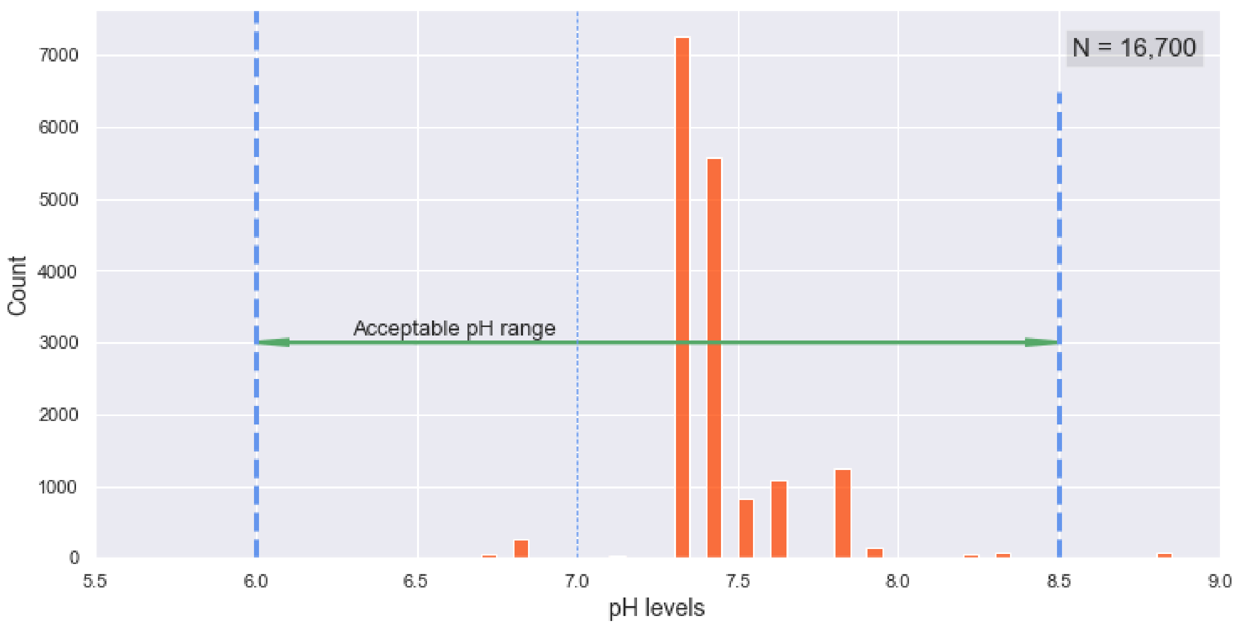


Source: The figure is based on the author's calculation using Google Maps and the locations of feedlots.

Water quality data (i.e., arsenic, salinity, nitrates, and nitrites) were obtained from National Water Information System (NWIS). The groundwater data were collected from roughly 1.5 million sites across all 50 states. Data for each location is available from the earliest record available in the database. In our study, groundwater quality data for the area closest to the feedlot was used by default.

Drinking water pH shows how acidic or alkaline it is. Pure water has a pH of 7.0. The pH values above 7 indicate alkalinity, while pH below 7 indicates acidity. It is recommended that beef cattle drink water with a pH range of 6.0 to 8.5 (Herring, 2014). Water at pH values outside the acceptable range may be hampered beef cattle productivity. Animals may suffer from acidosis and reduced feed intake if the pH falls below 5.5 (Schwartzkopf-Genswein et al., 2003). The already acidic conditions of the stomach make a low pH of water unlikely to affect beef cattle directly. Excessing alkaline water may induce a laxative effect and disrupt regular digestive activity. In contrast, an excessive amount of acidic water may cause acidosis and cause a reduction in feed intake (Owens et al., 1998). Among our samples, most drinking water pH values are within acceptable limits. Most beef cattle consume slightly alkaline water (Figure 2.6).

Figure 2.6. The Distribution of Potential of Hydrogen (pH)



Source The figure is based on county-level water quality data of USGS.

2.3 Methods

A Bayesian multilevel model was used to estimate the effect of heat and cold stress on beef carcass performance measures. The model is advantageous for handling an unobserved group effect within an individual-specific effect, different sizes, and repeated measurements (Park et al., 2004; Shor et al., 2007; Tamminen et al., 2016). Research data does not include specific information on producer-level feedlots, such as feeding styles, environmental stress management methods, and cattle types. As beef cattle production outcomes depend on each feedlot's feeding strategy, it was necessary to control for unobserved producer-level effects through a Bayesian multilevel model. The model outlined below is used to measure the relationship between livestock performance variables and weather, water quality, and economic variables related to cattle production,

$$(6)\ \text{Performance} = \text{Normal}\ (\alpha_{j[i]} + X\beta_{j[i]}\ ,\ \sigma_{j[i]}\ )$$

Where $j[i] = j'$, each feedlot $j' \in 1, \ldots, m$.

Performance = [Yield Index, Marbling Score]; X is a vector of the following independent variables: CCI_Heat and CCI_Cold represent the number of hours that CCI exceeds the points of heat and cold stress, respectively (Table 2.3); WQ_Arsenic, WQ_PH, WQ_NO_3, WQ_TDS, and WQ_Turbidity are measured indexes at cattle feedlot counties by USGS; PofCorn is the six-month moving average of the corn prices before cattle were processed. Individual feedlots are indexed across, and i is each carcass. This estimation model is with 2×9 parameters. We control for varying production styles by incorporating producers' county-level location and feedlot identification number in variables.

2.4. Estimation Results

Our estimation results show that weather stress harms beef carcass quality. The yield index increased with longer exposures to heat or cold stress, as shown in Table 1.4. This means more exposure to weather stress decreased meat quality. These findings align with Piao & Pack, 2015, who found that cattle exposed to severe winter weather conditions have increased yield indexes. Furthermore, the heat stress coefficient (0.00023) is larger, in absolute terms, than the cold stress coefficient (0.00019). Therefore, it is likely more important for feeders to manage heat stress than cold stress to preserve carcass performance.

Marbling scores were found to be negatively affected both by cold and heat stress. However, unlike yield index scores, marbling scores were more vulnerable to the effects of cold stress. Heat stress affects the marbling score by -0.00042 per hour, and cold stress affects -0.00068 per hour.

Table 2.4. The Estimation Results of the Bayesian Multilevel Model

	Yield index	P-value	Marbling Score	P-value
Hours of Heat Stress	0.00023*	0.076	-0.00042**	0.01
Hours of Cold Stress	0.00019**	0.02	-0.00069***	0.001
Minutes to Meat Processing Plant	0.0041***	0.001	-0.00004	0.734
Corn Price_6M Avg	-0.136***	0.001	0.328***	0.001
Hot Weight	0.00093***	0.001	-0.0021***	0.001
Arsenic	0.026***	0.001	0.032***	0.001
pH	-0.144***	0.001	0.173***	0.001
NO_3	0.0038***	0.001	0.063***	0.001
TDS	-0.001***	0.001	-0.0001***	0.001
Turbidity	-0.0023***	0.001	-0.0071***	0.001

Note: In parentheses, ***, **, and * indicate significance at 0.01, 0.05, and 0.1 levels.
Note that this result has the opposite sign to the coefficients on the yield index because a higher yield index is less desirable, and a higher marbling score is more desirable.

Managing weather stress is necessary for maintaining beef quality. Feeders may try to increase beef cattle's water intake in summer or feed in winter to handle this stress. Transportation stress was also found to impact carcass performance. The yield index slightly increased with transportation time (0.0041 per minute). However, no statistically significant relationship between transportation time and marbling scores was observed.

An increase in corn prices during the sampling period (Figure 2.1) positively impacted the marbling score, as shown in Table 1.4. This result is surprising as prior expectations were that cheaper corn would make higher marbling scores easier to obtain. It is possible that, as explained by Suh and Moss (2017), rising corn prices lead feeders to substitute away from corn with dried distillers grains and maintain a comparable diet. The yield index decreased, which is a desirable shift when corn prices increased. More research is needed on the relationship between feed prices and carcass quality.

Higher hot carcass weight resulted in a slightly higher yield grade and a lower marbling grade. Our results have similarities with Abraham et al. (1980), Bruns et al. (2004), and Hale et al. (2004). Larger beef cattle tend to have thicker fat and, therefore, a heavier ratio of internal organs. Excessive fat also reduces the percentage of the rib eye area, which is part of the marbling score and yield grade.

There have only been a few recent studies of water quality relationship to beef carcass characteristics. One interesting point was that the consumption of alkaline water improved beef cattle performance in our research. This confirms previous findings by Lancaster et al. (2019) that the pretreatment of low-quality roughages with alkaline fluids enhances digestibility.

The water quality estimation found that pH was related to the beef carcass performance. The arsenic, NO_3, TDS and Turbidity have limitations in interpreting results, although statistical analysis shows significant p-value values. For example, our statistical analysis indicates that toxic substances, such as arsenic and NO_3 are associated with improved marbling scores, but more research is needed to confirm this relationship. With weaker alkalinity water, the yield index is lowered by -0.144 per 1 degree of pH Additionally, the Marbling Score also demonstrated a positive relationship of 0.173 per 1 degree of pH, indicating that it promotes the improvement of the marbling state by increasing intake. These results should be conditioned on the fact that almost all water pH levels in the data were in the safe zone for beef cattle. It is unreasonable to assume that increasing pH would continue to positively impact carcass performance or animal well-being outside this safe range.

2.5 Expected Losses and Insurance Premium Rates

This research calculates a fair premium rate that could manage weather risk based on the number of extreme weather exposure hours using CCI. As CCI exposure hours is an objective index for livestock insurance, it cannot be affected by livestock producers and insurers. Using CCI exposure could reduce adverse selection and moral hazards relative to indemnity-based insurance. Index-based insurance only provides partial protection since it only covers a specific weather risk. We follow a process similar to Belasco et al. (2015) to determine the premium rate for a CCI Index insurance product. Specifically, we calculate the historical CCI from 1998 to 2015 to estimate the probability of extreme CCI levels. Using those probabilities, we calculate expected losses as follows:

$$(7)\ \text{Expected}[\text{loss}|\text{hours} > \text{S}] = \sum_{\text{h}=1}^{\text{H}} \text{Historic Probability}[\text{hours} = \text{S} + \text{h}] \times \text{Simulated}[\text{loss}|\text{hours} = \text{S} + \text{h}],$$

where h is the number of hours over S (Strike exposure hour level), while H is the maximum hours considered an upper limit.

We calculated the probability of heat stress and cold stress separately. Coefficient estimates from Table 2.4 were used to simulate the effect of heat and cold stress on yield index and marbling score outcomes. The yield index and marbling score were converted into monetary terms using historical premiums and value discounts of USDA grades relative to an outcome of Choice, Yield Grade 3 carcass. Premium rates for an insurance product based on weather-indexed losses were calculated using the simulated losses and hours exposed to weather stress.

Existing literature indicates that fluctuating temperatures significantly impact beef cattle production. Marbling scores could also be influenced by heat or cold stress. Initial values of the marbling score (5.0) and yield index (3.0) were assumed to calculate producers' losses due to heat and cold stress that worsen performance measures. Yield index and marbling score were simulated with rising hours exposed to heat and cold stress and, according to USDA standards, converted to yield and quality grades. Table 1.5 shows the averaged premiums and discounts for each grade in Figure 2.6. These premiums and discounts were used in Figure 2.6 in calculating simulated losses across weather-stress hours.

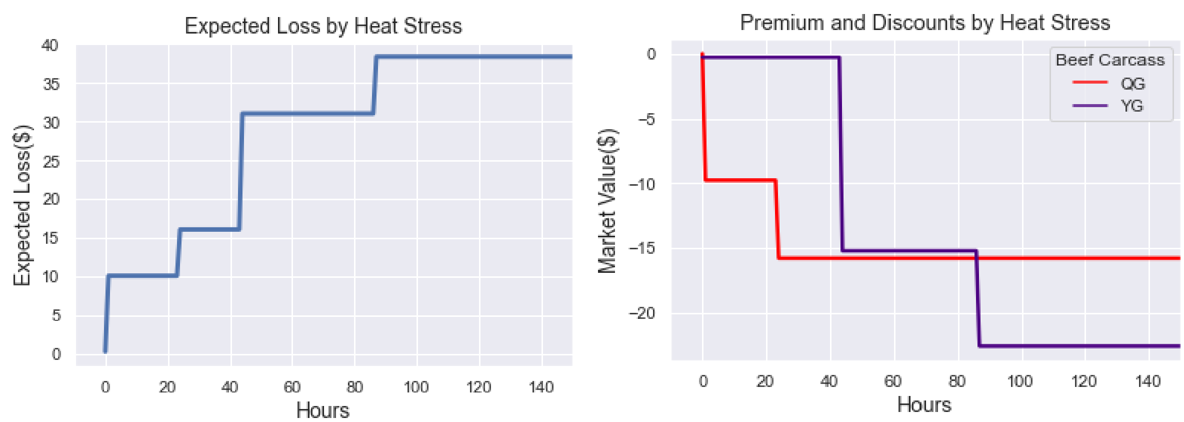
Table 2.5. The Average Premiums and Value Discounts by Quality and Yield Grade from May 2005 to October 2008

Quality Grade	Average Premiums/Discounts ($)	Yield grade	Average Premiums/Discounts ($)
Prime (8.0)	15.43	YG1 (1.99)	4.13
		YG2 (2.00-2.99)	2.00
Choice (5.0-7.9)	0.00	YG3 (3.00-3.99)	-0.30
Select (4.0-4.9)	-9.78	YG4 (4.00-4.99)	-15.22
Standard (3.9)	-15.79	YG5 (5.00)	-22.59

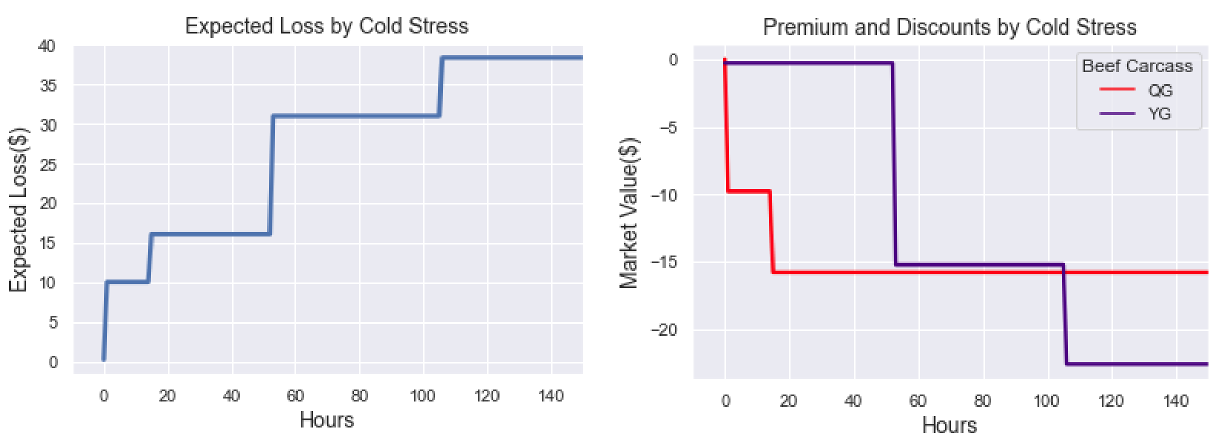
Data Source: USDA Agricultural Marketing Service

Figure 2.7. Expected Loss and Premiums of Value Discounts by Hours of Exposure in Response to Weather Stress

A. Case of Heat Stress



B. Case of Cold Stress



Source: The figure is based on the author's simulation using estimation results (Table 2.4).

As shown in Figure 2.4, the negative impact of heat stress on quality grade was not as significant as cold stress. Expected loss due to heat or cold stress increases with hours of exposure. Economic loss due to cold stress is seen as exposure nears 20 hours, slightly fewer hours than heat stress. It is important to note that these losses are due to carcass performance only. Other production-related issues could occur at the feedlot level due to weather stress.

Using weather data from a Midwest location from 1998 to 2015, Figure 2.7 shows the probability of hours exceeding the strike level. The indemnity is based on the number of hours the CCI threshold exceeds the strike. Expected losses determine a fair premium rate for such an event. Results in Table 1.6 indicate that individual premiums for diverse levels of cold stress at 2000, 2,300, and 2,500 hours are $2.60, $1.60, and $1.11, respectively. As insurance benefits are more likely to be received, the premium rate will increase.

Table 2.6. Premiums based on heat and cold stress levels

A. Heat Stress

Strike	Strike Percentile	Premium ($/cwt)	Premium ($/head)
1,500	62.1	1.21	9.08
1,600	65.6	1.02	7.65
1,700	69.1	0.91	6.83
1,800	73.1	0.74	5.55
1,900	78.8	0.65	4.86
2,000	85.1	0.49	3.68

Note: In order to calculate the premium per head, it was assumed that the hot weight of the beef carcass is 750 pounds.

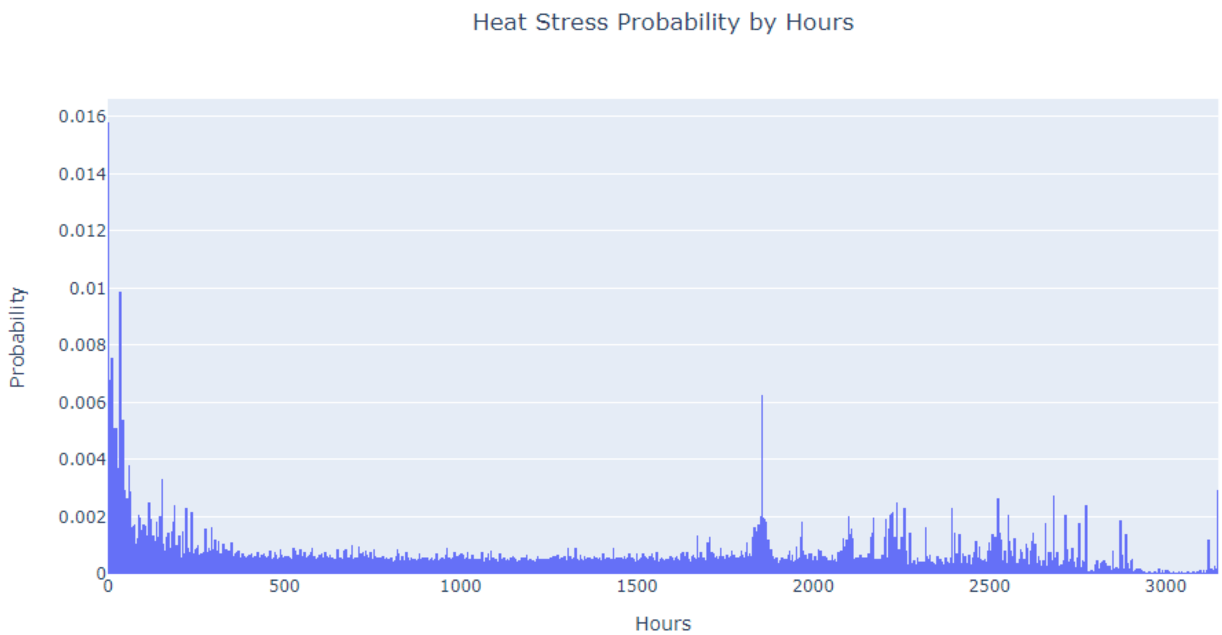
B. Cold Stress

Strike	Strike Percentile	Premium ($/cwt)	Premium ($/head)
2,000	74.3	2.60	19.46
2,100	77.1	2.31	17.35
2,200	80.4	1.98	14.84
2,300	84.1	1.60	12.03
2,400	86.4	1.38	10.31
2,500	89.0	1.11	8.36

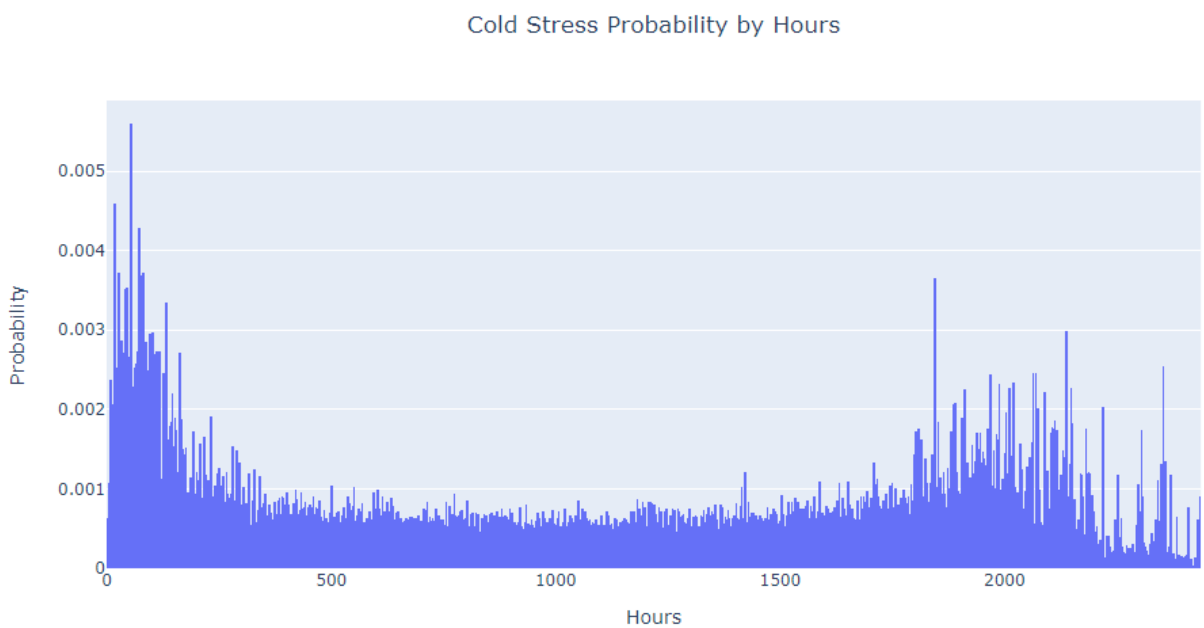
Note: In order to calculate the premium per head, it was assumed that the hot weight of the beef carcass is 750 pounds.

Figure 2.8. The Historical Density Probability of Heat and Cold Stress Exposure Hours in Western Iowa, 1998-2015

A. Case of Heat Stress



B. Case of Cold Stress



Source: The figure is based on historical NREL database.

2.6 Conclusion

The purpose of this study was to investigate how climate stress and water quality impacted beef cattle production: yield index and marbling score. Firstly, we observed an increase in the yield index when exposed to cold or heat stress. The marbling score was also worsened by heat and cold stress. More specifically, the heat stress impact is larger than cold stress on meat productivity, and the marbling score was more vulnerable to the effect of cold stress. According to the simulation analysis, weather stress steadily increased producers' losses, as weather stress increased carcass price discounts. To reduce producers' losses caused by severe weather conditions in the future, climate risk management in beef cattle production is essential. Existing strategies include modifying land use, changing animal feeding regimes, genetic selection, and changing breeds. Despite being effective at limiting the effects of climate stress, these strategies might not be sufficient to cover producers' financial losses by extreme weather. Policymakers should consider introducing weather index-based beef cattle insurance to mitigate the potential losses caused by extreme weather exposure.

The evaluation of heat and cold stress on the quality of beef carcasses used individual carcass-level data. The disadvantage of the meat processing plant data is that it does not contain climate data, which cannot be collected from feedlots. As a solution to this limitation, we obtained weather data from each feedlot according to its location six months before the processing date. The study also attempted to demonstrate that extreme cold or hot temperatures caused economic losses by negatively impacting carcass performance. Insurance premium rates were calculated to form the basis for designing livestock insurance based on the weather index.

In terms of water quality, increasing water pH was found to have a good effect on the beef carcass performance by supplying weak alkalinity substances in the feedlot. Analyzing the water content is relatively straightforward, but our estimation results with extreme weather may need to be approached with caution. The effect of sulfates on scouring decreases with an increase in alkalinity. A high sulfate concentration in water significantly reduced cattle intake of water and increased scouring (Grout et al., 2006), but the level of alkalinity could neutralize the level of sulfate (NRC, 1974). It seems necessary to confirm once more in future studies whether weak alkalinity water indirectly affects beep cattle performance.

We also confirmed that transportation stress hurts the yield index, but no significant relationship was observed between transportation and marbling scores. As transportation stress is short-term in our study, marbling is likely to change over a long period.

We are aware that our research may have limitations. One is that all carcass data were collected at a single plant. This means that common regional adaptations to weather stress (e.g., breed selection) likely do not vary widely across feedlots. Also, although travel time affects yield grade slightly, the average transport time is approximately four hours and does not vary considerably over our sample. Although we used some water quality data for estimation, long-term observation would be needed to precisely determine its effect on a beef carcass. In addition, to control water intake in response to changes in the external environment, more observational data are needed to control the surrounding environment other than the weather. Studying how water quality affects the performance of beef cattle requires follow-up studies after calves are born. By collecting data from feedlots and meat processing plants, future studies may improve these results. It will be possible to measure the impact of severe weather on cattle performance more precisely by analyzing feedlot data containing entry weight and placement time. For a feedlot's total losses to be calculated, it is also essential to count deaths from severe weather conditions. The meat processing plant data contains information about only those cattle that survived harsh weather conditions. Furthermore, producers would benefit from being informed on how they mitigated weather stress at feedlots. Under adverse weather conditions, producers' efforts to manage climate conditions could significantly affect carcass traits.

Chapter 3

Groundwater Permit Trading and Potential Groundwater Saving in Kansas

3.1 Introduction

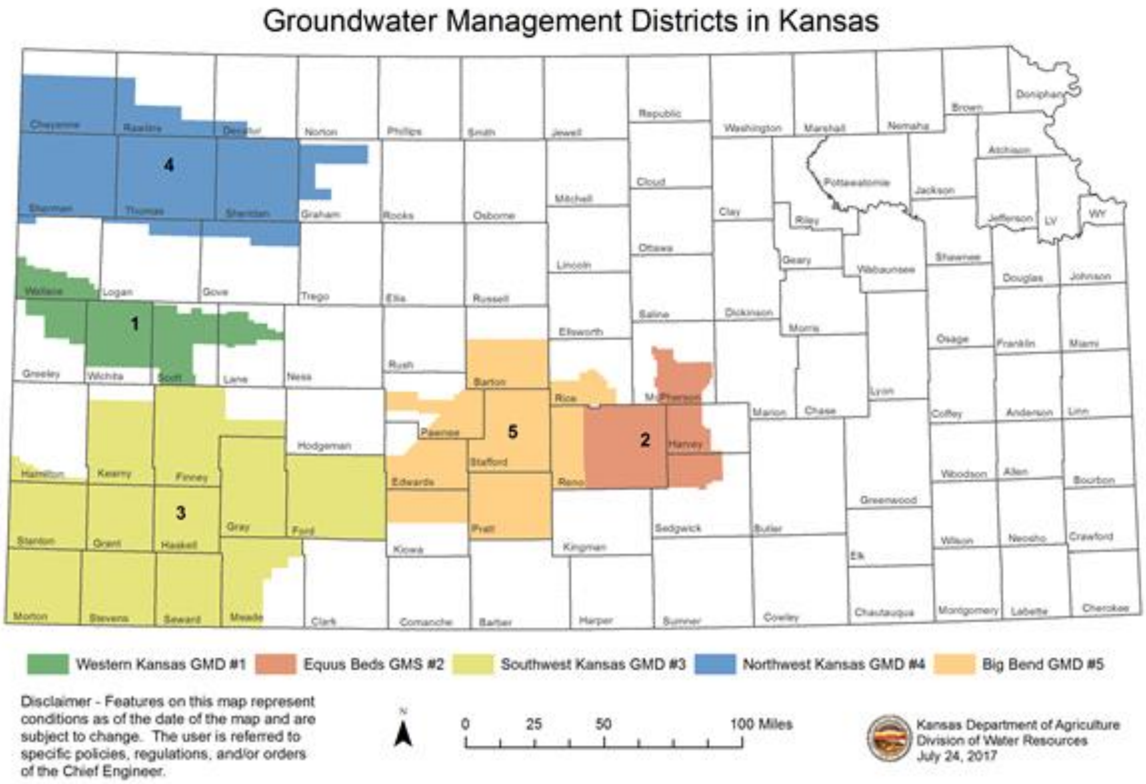
Groundwater is an essential resource in U.S. agriculture, and it supports approximately 50% of total irrigation (Dieter, 2018). The High Plain Aquifer (HPA)[3] spreads out across eight states from Texas to South Dakota, and more than 90% of irrigation use in this area relies on HPA (Salmon et al., 2015; Appendix A.1). For Kansas, agriculture contributes particularly heavily to the economy, accounting for $ 60 billion of the state's economy in 2021 (Kansas Department of Agriculture [KDA], 2021) and irrigation, using water drawn from HPA, is crucial for crop production. It is estimated that irrigation added $3.9 billion to 2019 Wester Kansas farmland (Hendricks & Sampson, 2022). Ninety-six percent of groundwater extracted from HPA has been used for irrigation, and 76.5% of farms rely on groundwater for irrigation in Kansas (KDA, 2013). The current rate of groundwater is predicted to deplete approximately 70% of HPA within 50 years (Steward et al., 2009).

The Kansas State government recognizes groundwater depletion as a serious threat to the Kansas economy and has introduced and continued to amend groundwater management laws. In 1945, Kansas started to enact new legislation by the principle of prior appropriation, the Kansas

[3] The High Plains Aquifer is also referred to as the Ogalalla Aquifer.

Water Appropriation Act (KWAA), for groundwater management. The Chief Engineer of the Water Resources Division (DWR, K.S.A. 82a-706) was appointed to begin managing all groundwater and surface water in Kansas. Under this regulation, all water users must obtain water rights from DWR limiting authorized annual water use. This bill has divided groundwater rights into vested and appropriation water rights. Vested water rights were granted to farmers who had used groundwater before June 23, 1945. Vested rights have seniority over appropriation rights. In 1972, the Kansas Groundwater Management District Act (KGMDA) was enacted by K.S.A. 82a-1020 et seq. as a bottom-up approach to groundwater regulations. Kansas has five groundwater management districts (GMDs). Each GMD is governed by a board of directors elected by local groundwater users (Figure 3.1). Most of the HPA area in Kansas is covered by GMDs. Each GMD has authority over a draft regulation of groundwater use or a property transaction, including water rights.

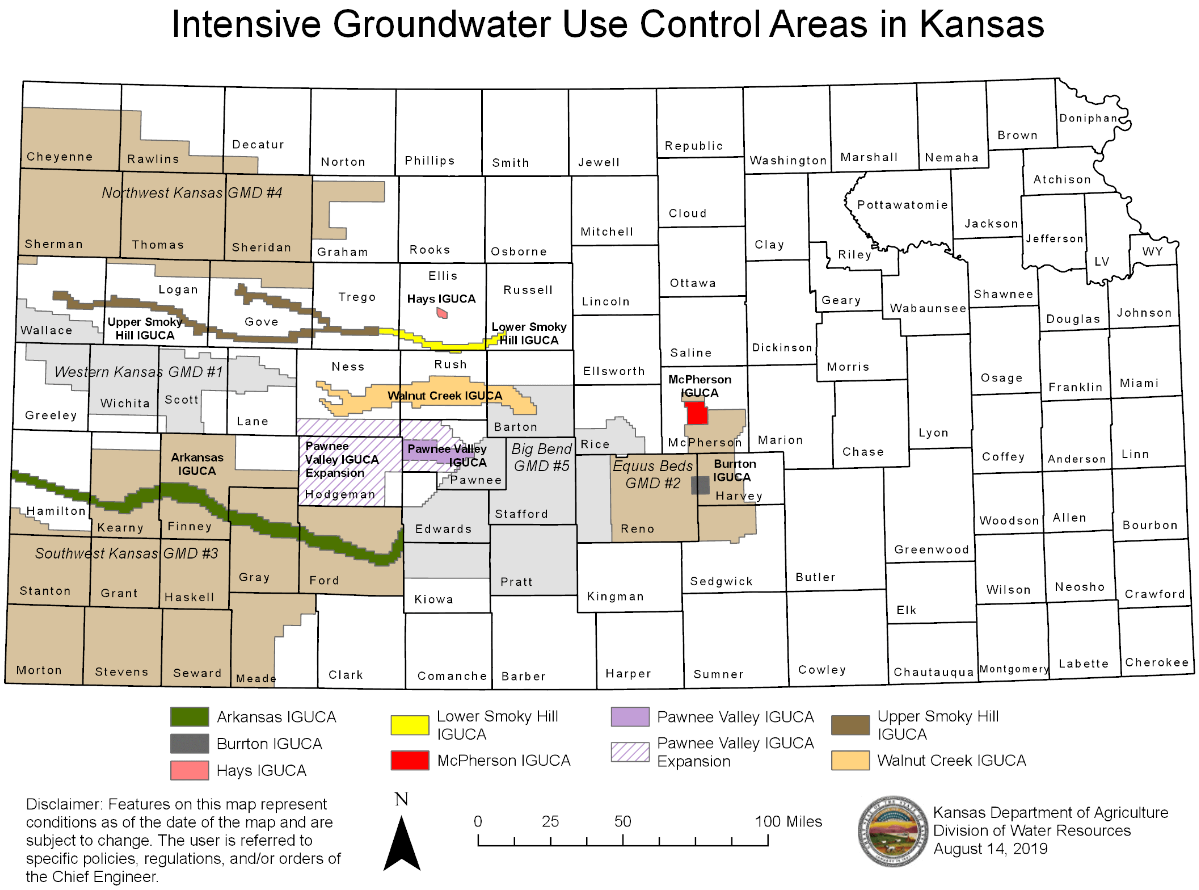
Figure 3.1. Groundwater Management Districts in Kansas



Source: Kansas Department of Agriculture, available at: https://agriculture.ks.gov/divisions-programs/dwr/managing-kansas-water-resources/groundwater-management-districts

Despite these legal efforts, groundwater depletion in some Kansas areas has become increasingly severe and may require more stringent regulation. There has been some movement to amend the existing water management law (KGMDA). In 1978, Intensive Groundwater Use Control Areas (IGUCA), as a top-down approach, was introduced by the Chief Engineer of DWR to a region suffering from reduced surface water availability (Figure 3.2). IGUCA is currently established in eight areas and is under review in another (KDA, 2022).

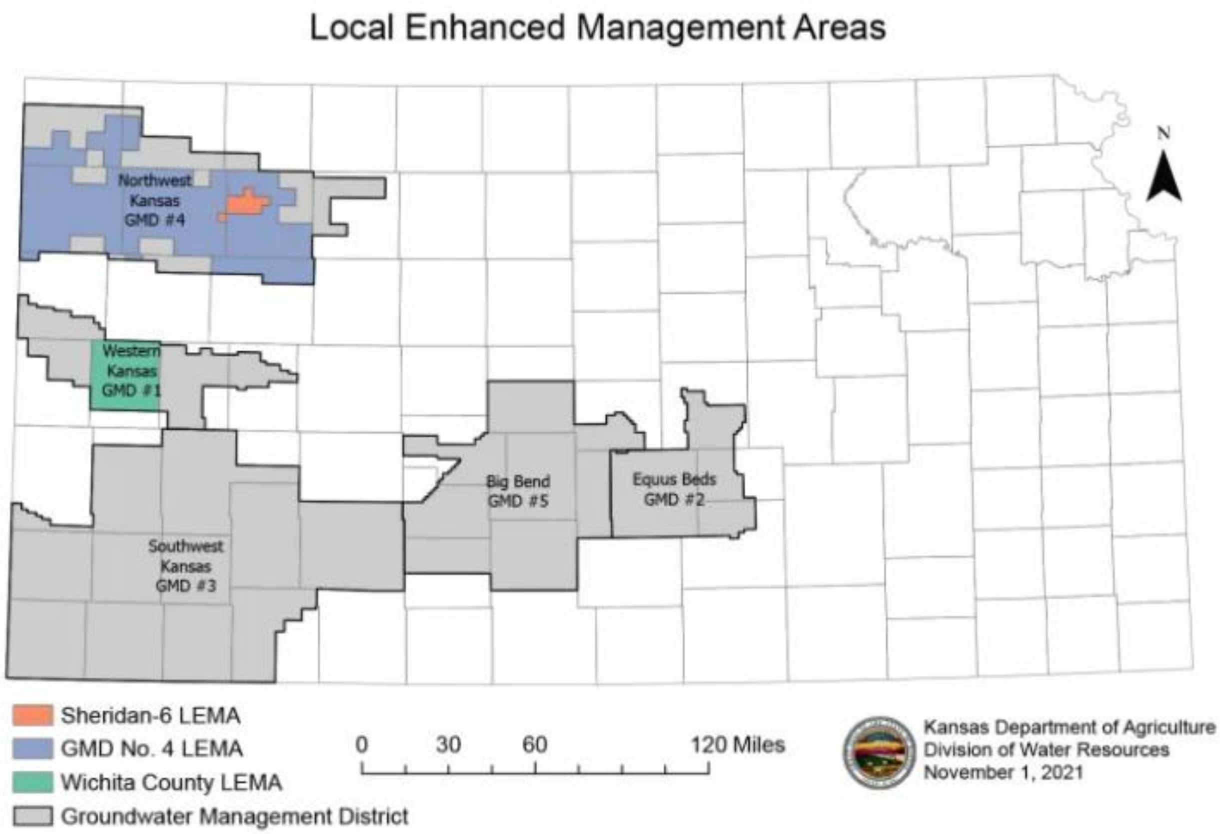
Figure 3.2. Intensive Groundwater Use Control Area in Kansas



Source: Kansas Department of Agriculture, available at: https://agriculture.ks.gov/divisions-programs/dwr/managing-kansas-water-resources/intensive-groundwater-use-control-areas

Active participation of water users is essential for effective groundwater management. With this in mind, a bottom-up approach led to the creation of Local Enhanced Management Areas (LEMA) in 2012 (Figure 3.3).

Figure 3.3. Local Enhanced Management Areas in Kansas



Source: Kansas Legislative Research Department, available at: https://klrd.org/publications/briefing-book-2022/local-enhanced-management-areas-lemas/

There are two steps to the establishment of a LEMA. First, groundwater users in areas with severe groundwater depletion send petitions for more robust management. Then, the Chief Engineer assesses the petition and may order the introduction of LEMA. Under LEMA, groundwater users have to reduce their total usage by 20 % but have the flexibility to measure use across a five-year period. For example, if you use less in one year, you will be able to use more in another year during the five–year period. The Water Conservation Areas (WCA) initiative was implemented in 2015 in order to encourage more groundwater users to participate in water-saving management systems. (K.S.A. 82a-745). The distinction between LEMA and WCA is that WCA allows individuals to join directly in water-saving programs. Legal efforts of the state of Kansas have been evaluated to be innovative, constantly reflecting reality and developing groundwater management (Peck, 2004; Sophocleous, 2012).

The practical effectiveness of water regulation based on pumping limits in Kansas has been thoroughly analyzed by recent studies (Drysdale & Hendricks, 2018; Golden & Guerrero, 2017; Golden & Leatherman, 2019). Golden and Leatherman (2019) find that there is no economic damage generated by water use restrictions in Walnut Creek IGUCA. Farmers switch to more profitable crops in response to groundwater restrictions and introduce new irrigation technology for water conservation. Golden and Guerrero (2017) find a 21% reduction in agricultural water use with only a decline of approximately 10% in irrigated acres in Sheridan county 6 LEMA. The rate of decrease in farmland use in the LEMA area was lower than in the non-LEMA area. It is evident from the above example that the LEMA system reaches irrigation water savings while minimizing the impact on farm productivity. These results indicate the effectiveness of farmers' selective strategies. Drysdale and Hendricks (2018) report that farmers' strategic behavior changed following the introduction of LEMA in Sheridan county. For example, farmers reduce irrigation water use by 26% by changing irrigation acres, using intensive irrigation water, and selecting crops that require lower irrigation water use.

Even though empirical studies support the effectiveness of IGUCA and LEMA (Pope, 1991; Peck, 2004; Sophocleous, 2012; Golden & Guerrero, 2017; Butler et al., 2018; Golden & Leatherman, 2019; Zwickle et al., 2021), these two management systems are not widely adopted in other Kansas areas. Six of the nine IGUCAs are located outside the GMDs. Sheridan County 6 LEMA was a small region of the GMD4, and then GMD4 District-Wide LEMA expanded many areas of GMD4. Wichita County LEMA has been in place since 2021 in the northern part of GMD1

(Figure 3.3). Introducing IGUCA or LEMA is challenging to implement when opposing opinions of groundwater users clash. For example, the Rattlesnake/Quivira LEMA in GMD5 development has been suspended. Also, although LEMA can legally extend the entire GMD4 area by the Gove County District Court ruling on October 15, 2019 (Friesen v. Barfield 2019[4]), establishment in this area has been slow due to appeals to higher courts. Legal, political, and user risks are obstacles to establishing these innovative water regulations across Kansas. First, a groundwater use reduction order in many constitutes an uncompensated taking under the 5th and 14th Amendments of the U.S. Constitution (Peck, 1994; Peck, 2019). In this case, the state of Kansas may have to compensate groundwater users for property infringement. Second, the Chief Engineer of DWR can only execute an investigation at the request of water rights holders and cannot proactively protect the HPA (Griggs, 2014). As central irrigators have decision-making powers within GMDs, the Chief Engineer has no incentive to oppose them politically. Third, requesting an impairment investigation [5]by one water right holder could reduce a neighbor permit holder's groundwater use (Griggs, 2014). Senior water rights holders who obtained water permits before 1964 always have priority over junior water holders when they are in water use conflict. The number of groundwater permits and authorized quantities continues to rise (Figure 3.4). The pumping limit regulations may not work correctly due to economic and political reasons.

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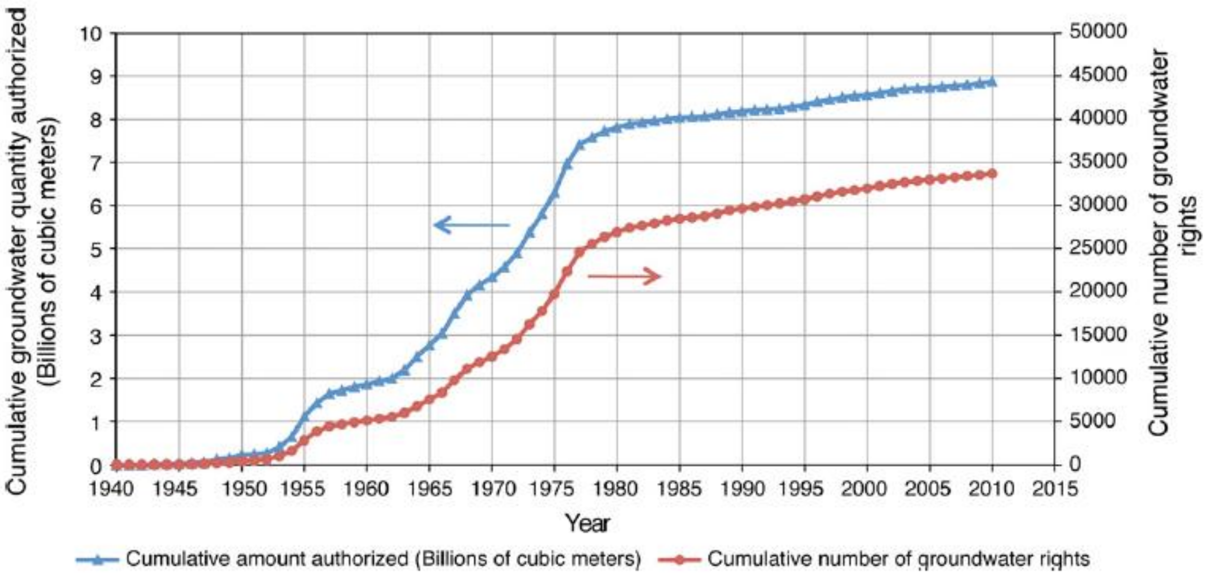
[4] Available from https://agriculture.ks.gov/docs/default-source/dwr-water-appropriation-documents/2019-11-12-friesen-motion-to-alter-or-amend_83816.pdf?sfvrsn=6e288ec1_0

[5] In Kansas, water law is governed by the principle "first in time, first in right.". A priority date is assigned to water rights to determine who has the first water right. If water is scarce, water rights belonging to those with more senior rights will be satisfied first before rights belonging to those with junior rights. By doing this, the Division of Water Resources can protect those who have established rights first from those who are coming along after them. Under Kansas law (K.S.A. 82a-706b and K.A.R. 5-4-1), it is required to redistribute water between users when a more senior right is being impaired.

Figure 3.4. Accumulated Number of Groundwater Rights and Authorized Groundwater Quantities in Kansas



Source: Sorphocleous (2012)

As awareness of the limitations of centralized governance approaches based on pumping restrictions has grown, localized and decentralized market-based approaches have gained popularity. Although the debate over groundwater management methods remains, market-based approaches have been shown to combine voluntary participation and economic efficiency (Chong & Sunding, 2006). There has been little research regarding permit trading in Kansas. Guilfoos et al. (2016) compared five groundwater policies (flat tax, variable tax, quantity restriction, water market, and local area management scenarios) with the net-benefit calculations. They show that reducing groundwater use in the water market has a similar achievement to restriction-based taxation. These results were based upon groundwater demand data, and, to our knowledge, no study exists that focuses on the relationship between the marginal value of groundwater and permit trading. Based on actual water use, we estimate the marginal value of groundwater in each well.

The data comes from the Water Information Management and Analysis System (WIMAS). This WIMAS contains water right details, point of diversion details, and water use details, including crop type and cropland size. The analysis of each crop production and potential revenue is based on the Crop Water Allocator (CWA) developed by sKSRE. CWA is a crop-water production function based on 30 years of accumulated crop production data in Western Kansas. The CWA provides quadratic production models to enable the measurement of groundwater's marginal value through differentiation.

The primary purpose of this study is to quantify the marginal value of groundwater and assess the possibility of permit trading to reduce groundwater extraction without financial damage to producers. The motivation for this study comes from the strategic behavior of irrigation water users at Sheridan County 6 LEMA. Under the LEMA, farmers can transfer their unused irrigation water from the first period (2013-2017) to the second period (2018-2022) at a maximum of 5 inches per acre. The farmers save over five inches of groundwater that can be carried over to the second period. However, the remaining groundwater that cannot be carried over shows a different pattern of overuse than the typical pattern of the first period. (Drysdale & Hendricks, 2018). Farmers actively participate in the conservation of irrigation water when economic motivation is clear by transferring 5 inches of groundwater, but they tend to overuse groundwater in the absence of such economic motivation. A market-based approach to groundwater management should be able to continually provide farmers with economic incentives and handle the over-extraction of groundwater.

We utilized a quantitative approach to examine whether the groundwater trading system can cope with the current depletion of groundwater that Kansas is facing without lowering farmers' income. The trading system allows farms with low marginal value of groundwater irrigation to sell their pumping rights to users whose crop production has higher marginal values of irrigation. In this way, both parties are better off, and water use is not increased.

3.2 Background

3.2.1 Economic efficiency of water permits trading

Groundwater for irrigation is a crucial input for crop production in the Midwest Midwest farmers relies heavily on the HPA for irrigation. When water use is competitive among farmers, excluding rival users can be rational and economically beneficial. Therefore, water resources are particularly challenging in terms of defining property rights. Kansas has the "first-in-time, first-in-right" doctrine of water law to appropriate water rights. Water supplies for an irrigation area are determined by prior appropriations. Unfortunately, peak water consumption often does not coincide with a high water supply. Aridity is a dominant feature of the Midwest because of the low rainfall in the region. Water laws are typically simple when water is abundant, and they are rarely enforced. As long as water supplies are claimed for revenue-generating, the centralized system can be forced to use resources to establish exclusion water use rights (Randall, 1981). It may be reasonable to devise more elaborate allocation strategies and satisfactory solutions if water is in short supply (Young, 1986).

Different allocation mechanisms, including water markets, are being considered as demand for groundwater grows. A market for water rights has several key benefits, including efficiencies in spatial and temporal allocation and potential decreases in water use. A decentralized system of reallocating water and water rights would accommodate individual decision-making and encourage water conservation (Bell et al., 2008). A market-based system is flexible and allows shifts in crop production as crop prices change. As a result of water markets, water rights and water use are efficiently allocated, and water is reallocated from low to high-value activities (Howitt & Hansen, 2005). It is said that water allocation is economically efficient if there is no redistribution of the water that is more beneficial for society. The water market is a relatively straightforward mechanism to exchange rights when the value of water differs between owners and buyers, and the value difference exceeds the cost of more water (Goemans & Pritchett, 2014).

3.2.2 Requirement of groundwater permit trading

Although surface and groundwater management share some similarities, they differ substantially. Challenges to groundwater management involve adjusting pumping allocations to satisfy users while complying with groundwater rights law; monitoring and enforcing groundwater use on private farmlands; understanding the nature of groundwater behavior; dealing with delayed impacts of water extraction. Complicated geophysical processes connect groundwater pumping and aquifer movement flow. It is often difficult to accurately measure groundwater variables and properties but doing so is essential to management. A significant challenge for quantifying or monitoring groundwater use is that groundwater is primarily extracted from and conveyed over privately owned lands (Babbitt et al., 2017). Therefore, current pumping behavior can have long-term consequences for the system, depending on its hydrology.

Most Midwest agricultural communities and well owners obtain their drinking and irrigation water from groundwater wells. Groundwater pumping control could require limiting agriculture production, changing regulations, or funding for new irrigation technologies. This may negatively influence the local economy by placing high costs on groundwater users. Trading groundwater has the potential to offer an affordable solution to groundwater sustainability. The aggregate pumping limit is determined within a trading program by analyzing acceptable aquifer levels, and individuals are allotted some amount from the total as an allocation. If farmers do not use all of their allocations, they may lease the rest or permanently sell them. If they exceed their quota, there is the option to rent or buy from another user whose d allocation is not depleted. In short, a market system allows the transfer of groundwater to be used at the time and place it is most valued. In contrast to top-down regulation, the market-based approach provides groundwater users with more freedom and flexibility to reach groundwater management goals voluntarily (Chong & Sunding, 2006). Furthermore, groundwater can be monetized through a trading program in order to compensate individuals for conservation and better control of aquifers (Brozovic & Young, 2014).

The water market concept emerged as the economic value of water changed in the 1970s (Chong & Sunding, 2006). Water was no longer treated as a public good but as a private good because the supply-side water policies such as finding new water sources and redirecting water to new demands could not meet demand. Furthermore, prior appropriation, the predominant water rights system in the U.S., provides weak incentives for water conservation.

Chong and Sunding (2006) have shown economic inefficiency by comparing social welfare due to different marginal water values before and after surface water trading. In addition, they offered guidance on how to set up conditions for successful water trade. First, the "no injury" rule should be the default condition to prevent damage to third parties outside the water trade. Trading permits should not directly or indirectly harm neighboring wells by excessive groundwater use. Second, a single price in the water market would allow for the appropriate water distribution between low-value and higher-value uses. Third, the analysis should consider water supply cut, cropping patterns, water availability, and productivity among regions.

Fisher-Vanden and Olmstead (2013) analyzed the reasons for the success of the air quality market over 40 years. Then, considering the physical, legal, and economic differences between air and water, they provide six conditions for a viable water quality market. Our study assumes that over-extraction damages groundwater aquifers, and then we consider excessive use of groundwater as a kind of environmental pollution. The first condition is non-uniform mixing because pollution causes additional damage everywhere, and it is essential to know where it is generated. Groundwater's nature causes excessive use at one location to eventually lead to the fall of the groundwater level, causing damage to nearby users. To prevent that from happening, we must find out where the groundwater is being over-used. Measurement, monitoring, and enforcement are important administrative activities. In order to make permit trading more efficient, prices can be based on location-specific marginal benefits of wells. Montgomery (1972) first proposed this location-based approach in the seminal research regarding air quality trading. The last condition of a working water market is sufficient trading volume.

Babbitt et al. (2017) suggest several factors that contribute to the success of groundwater permit trading markets. First, the key to a flourishing groundwater market is a transparent and inclusive process of engaging groundwater users. A transparent process should reduce disagreements and reduce the likelihood of costly modifications later when issues arise. Second, a clear set of goals and results will aid in improving groundwater trading programs (Babbitt et al., 2018). Third, initiating and enforcing groundwater allocations is required for promoting trading programs. Fourth, a trading program must create extra monetary incentives for the groundwater user who oppose the top-down approaches (Matthews, 2017). Fifth, groundwater use must be measured to accurately assess the impact of allocations on the groundwater trading market. Incentives would be provided by volume-based trading to encourage reductions in water use per acre, as unused allocations are quantifiable and marketable. It is possible to monitor and enforce volumetric allocations and transactions, but the equipment and resources needed can be costly. Finally, a trading program should rely on a thorough understanding of aquifer dynamics, such as groundwater movement and level. Groundwater recharge plans will be a fundamental instrument to meet the initial goals of groundwater management, but any recharge plan would have to comply with state water law.

Permit holders of Kansas groundwater are required to submit data annually to the DWR Chief Engineer. Data include authorized water quantities, actual water usage, pumping rates, location of use, diversion point, authorized irrigation land size, actual land use, and crop selections[6]. Location-based trading is possible with meters installed in all groundwater wells. As Kansas groundwater regulations currently impose penalties on over-users, this is consistent with desirable measurement, monitoring, and enforcement conditions. According to previous studies, the Kansas groundwater management system complies with the requirements for the water market suggested by Fisher-Vanden and Olmstead (2013). In particular, the metering system installed in each groundwater well and the management agency's penalty for excessive use can allow a fair groundwater transaction.

3.2.3 Water Market Research in the Midwest

Many studies well recognize water markets for their economic efficiency and optimal distribution (Young, 1986; Sunding et al., 2002; Zilberman & Schoengold, 2005; Chong & Sunding, 2006; Palazzo & Brozovic, 2014; Wang, 2018). However, most research on water trading

[6] According to Kansas Water Appropriation Act (K.R.A. 5-14-12), penalties for violations against overpumping can be $1000 per day and up to four years of groundwater use suspension. Each well is equipped with a piece of measuring equipment, so the well will be inspected randomly to see if it has been appropriately reported during the inspection. Violations are also heavily punished.

has covered surface water trading, and a few studies have been conducted on groundwater trading. (Chong & Sunding, 2006). Bruno and Sexton (2020) pointed out that the economic approach of groundwater management is relatively less popular than control-based management methods. Howe and Goemans (2003) investigated how different institutional systems can influence the types and volume of transfer water permits in the Arkansas River Basin and South Platte of Colorado. In the absence of a water court review, trading became active when it had a homogenous nature and reduced transaction costs and uncertainty about its success. The findings of this study suggest that additional market assistance should be provided when conditions in the basin are similar to those in Arkansas.

Thompson et al. (2009) confirmed that groundwater trading in Nebraska could reduce irrigation water use and show the economic effects of groundwater transactions when permit trading was activated. There was a reduction of 40 percent in water use that was observed with groundwater trading compared to the unrestricted pumping policy because of the size of allocations. Stewards et al. (2009) evaluated the Kansas groundwater policy (existing IGUCA and Water Conservation Assistance Program) using a mixture of hydro-groundwater and economics models. They used Gisser and Sanchez's bathtub model, in which well-parcel groundwater usage and economic efficiency were measured using geospatial data. They found that the three policies, such as existing water use regulation, and buy-back program, affected farm income and induced reducing groundwater use. Impacts varied from region to region.

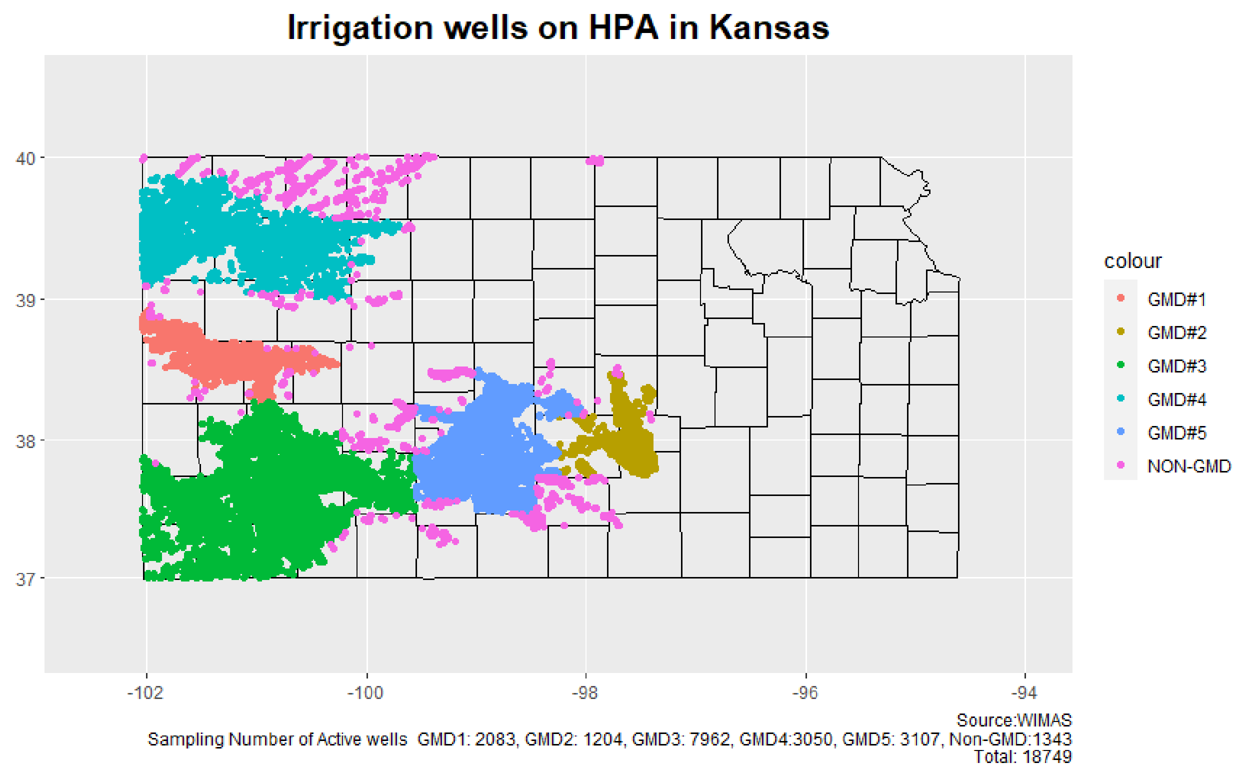
3.3 Methods

3.3.1 Data

Data were collected through the use of the 2018 Water Information Management and

Analysis System (WIMAS) in Kansas. This WIMAS data consist of Water Right Details, Point of Diversion Details, Authorized Quantity & Rate, and Reported Water Use from 2018. Water Right Details consist of water source, total acres authorized, water right status, and the place of use. In the Reported Water Use category, groundwater owners must report more specific information on groundwater use annually. They report information on total water used, actual acres irrigated, and crops planted. We used the latitude and longitude of each irrigation well, the quantity of authorized water, authorized acres, the amount of actual water, actual acres used, and crop choice information from Reported Water Use. The locations of the Kansas irrigation wells are shown in Figure 3.5. There are 18,749 groundwater wells, and 1,343 irrigation wells do not belong to a GMD. There were 2,083 irrigation wells in GDM1 and 1,204 in GMD2, 7,962 in GMD3, 3,050 in GMD4, and 3,107 in GMD5. Water use reported by owners of irrigation wells to WIMAS is shown in Table 2.1. We analyzed six representative crops (alfalfa, corn, wheat, sorghum, soybean, and sunflower) grown in Western Kansas based on WIMAS. Crop prices were collected from the United States Department of Agriculture Economic Research Service (ERS).

Figure 3.5. The Irrigation Well Distribution in Kansas



Source: The figure is based on the author's work using Water Information Management and Analysis System, available at: https://geohydro.kgs.ku.edu/geohydro/wimas/

3.3.2 Crop Water Production Functions

The production functions of crops can be used to explain the yield response to water. The crop-water production functions can be calculated using field data and simulations based on observed data (Vaux & Pruitt, 1983). When the soil water availability is not limited, the crop water requirement is the maximum amount of water to be productive. Plants need water access for cooling designs; most of the root's water uptake is evaporated through transpiration, and only a tiny portion is available for crop growth (Brouwer & Heibloem, 1986). Evaporation and transpiration are two separate processes by which water is lost from the soil surface (Gates, 1980). The crop cannot use any additional water beyond evapotranspiration (ET), so its water use per unit yield is calculated by determining its outcome and total water usage. This is a fundamental concept of the crop-water production function (Schneekloth & Andales, 2017). We use the crop-water production function to predict crop yield based on the results of previous studies since water is a crucial factor for plant growth.

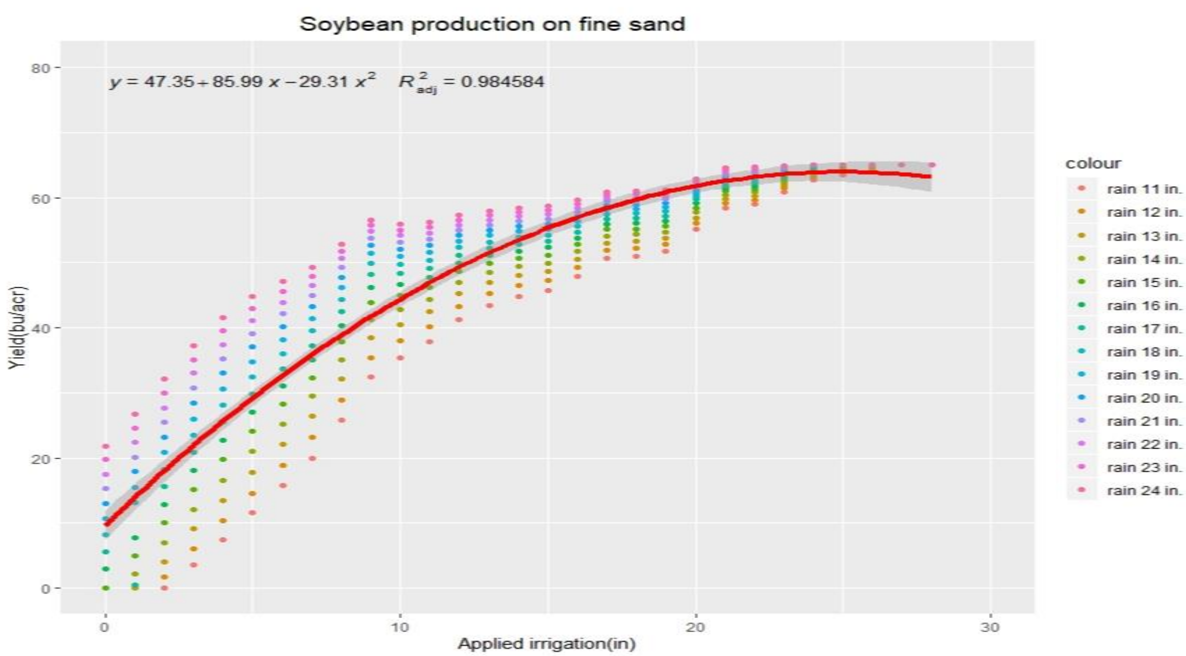
Table 3.1. Summary Statistics of Water Use

	Mean	Std. Dev	Min	Max	Obs #
Authorized Quantity (Acre-foot)	271.02	202.89	0	2560	18749
Non-GMDs	119.07	91.87	0	952	1343
GMD 1	295.96	197.22	0	1914.98	2083
GMD2	122.32	65.13	0	419.9	1204
GMD 3	368.77	237.02	0	2560	7962
GMD 4	244.17	126.88	0	1360	3050
GMD 5	166.88	65.55	0	930	3107
Actual Water Use (Acre-foot)	95.11	99.17	0	939.91	18749
Non-GMDs	51.94	59.99	0	325.35	1343
GMD 1	36.75	57.5	0	433.72	2083
GMD2	74.22	62.25	0	292	1204
GMD 3	115.87	125.53	0	939.91	7962
GMD 4	84.77	64.87	0	610	3050
GMD 5	117.1	70.99	0	383.17	3107
Authorized Acres	395	56843	2	8095	18749
Non-GMDs	180.48	142.36	4.4	780	1343
GMD 1	486.41	446.24	20	3507.24	2083
GMD2	140.33	84.35	3	842.96	1204
GMD 3	574.64	785.48	4	8095	7962
GMD 4	307.09	224.38	2	1593	3050
GMD 5	176.15	101.18	6	1857.1	3107
Actual Land Use	96.95	94.34	0	1044	18749
Non-GMDs	56.66	59.68	0	475	1343
GMD 1	54.61	78.75	0	647	2083
GMD2	75.76	58.02	0	269	1204
GMD 3	111.01	118.42	0	993	7962
GMD 4	110.87	75.96	0	1044	3050
GMD 5	101.82	53.58	0	380	3107

Data source: Kansas Geological Survey [KGS] WIMAS

We used local crop-water production functions (Klocke et al., 2006) based on Crop Water Allocator (CWA) developed by Kansas State Research and Extension (KSRE). CWA offers crop-water production functions (Klocke et al., 2006) based on thirty years of accumulated crop production data from Western Kansas. In general, crop yield increases linearly with increasing water supply, up to about 50% of water application requirements (Solomon, 1985; Forster & Brozovic, 2018). The function eventually exhibits a quadratic form as returns to addition water diminish (Llewelyn & Featherstone, 1997; Klocke et al., 2006) (Figure 3.6). CWA supports six popular crops (alfalfa, corn, wheat, sorghum, soybean, and sunflower) and three soil types (Silt loam, Fine sand, and Loamy sand).

Figure 3.6. An Example of Crop-Water Production Function



Source: The figure is based on the author’s calculation using Crop Water Allocator, available at: https://milab.ksu.edu/crop-water-allocator

3.3.3 Economic analysis of groundwater value

This economic analysis follows Sunding et al. (2002), but the details are revised for the Kansas situation. This microeconomic model assumes that each farmer has a different amount of cropland and multiple crop choices. Each farm has its own indicator (i), assuming that i = 1, ..., I. Farmers report their cropland acres to WIMAS. Crops are indexed j=1,…, J. We analyze six crops commonly grown in Western Kansas. Farmers plant multiple crops on the available cropland. Each farmer's cropland constraint is denoted $l_i = \sum_{j=1}^{J} l_j$, where l is acres of cropland available. No assumptions are made about the groundwater flow between farms. However, we assume spatial barriers to water trade and only allow trade between farms in the same GMD. Scenario indicators are s = 0,1, ..., S, where 0 is a non-pumping restriction. Let a^n be the regional area indicator, so that a^n=1,…,A^n. The set of farmers in an area a^n is indicated as B_n^k. For instance, if we have nine farmers in the three area boundaries under a scenario n, then B_1^n ={1,2,3}, B_2^n={4,5,6}, and B_3^n={7,8,9}. Each farmer has the initial permitted quantity of groundwater $\overline{g_i}$. Let g_i^0 be an unregulated groundwater use and g_i be an actual groundwater use. In the basic scenario, the total amount of irrigation water availability in an area a^n is $\sum_{i \in B_k^0} G_{0i}$. It is assumed that the actual water usage is equal to or less than the permitted groundwater usage, and the authorized groundwater usage (g_{ij}) is less than the unregulated groundwater use (g_{ij}^0), such as $g_{ij} < g_{ij}^0$.

The strategic behavior of farmers responding to groundwater use reduction in this study is followed by the empirical evidence in Sheridan County 6 LEMA and Walnut Creek IGUCA. Farmers adopt efficient water application technologies to prepare for reduced agricultural water use (Drysdale & Hendricks, 2018; Golden & Leatherman, 2019). Farmers also tend to change to more valuable crops (Golden & Leatherman, 2019) or change groundwater use patterns on the same crop (Drysdale & Hendricks, 2018). Each crop production per acre as y_{ij} is determined by soil type (st), amount of groundwater (g) by the crop-water production function. The production function for each crop is derived as a quadratic function using CWA.

$$y_{ij} = f_j(\, st_i, g_i)$$

The total output Y_i consist of production per acre y_{ij} and cropland acre l_{ij}.

$$Y_i = \sum_{j=1}^{J} (y_{ij} * l_{ij})$$

In microeconomics, humans behave rationally. This assumption is valid in our analysis and assumes that farmers make reasonable judgments for their revenue-making. We also assume that farmers are price-takers in terms of purchasing inputs and selling each crop at its market price. This hypothesis assumes that Kansas farmers are sensitive to changes in crop prices. The revenue of farmers with each irrigation well is

$$R_i = \sum_{j=1}^{J} P_j * Y_{ij}$$

such that

$$\sum_{j=1}^{J} AW_{ij} \leq G_i \qquad (1)$$

$$G_i \; < \; G_0 \qquad (2)$$

$$\sum_{j=1}^{J} l_{ij} \leq l_i \qquad (3)$$

The first constraint explains that actual irrigation water cannot exceed the authorized groundwater quantity. The second constraint is that the authorized groundwater quantity is less than the unregulated groundwater use. The third constraint is the cropland availability of each irrigation well. Let l_{ij} be the amount of cropland to the production of crop j at an irrigation well of farm i. In this study, we consider two situations. First, each irrigation well allows unlimited groundwater use. In this case, farmers maximize their revenue (R_i^0). In the second case, we assume the state of Kansas places a limit on groundwater use. As each irrigation well has an authorized groundwater quantity, farmers try to maximize revenue subject to pumping limitations (R_i). From this revenue and amount of groundwater use change, we get the marginal revenue change due to the impact of groundwater regulation.

$$Marginal\ revenue_i = \frac{R_i^0 - R_i}{AW_i^0 - AW_i}$$

Reduced groundwater use results in a reduction in marginal revenue. The location-specific marginal damage from each irrigation well in this study identifies heterogeneity of damage along the groundwater aquifer. The original paper on permit trading (Montgomery, 1972) considers this heterogeneity essential for the success of permit trading (Fisher-Vanden & Olmstead, 2013). Unfortunately, many permit trading studies do not account for heterogeneities due to the difficulties of identifying specific points of damage and measuring the specific marginal cost (Farrow et al., 2005; Wang, 2018). Our irrigation well-based permit trading can explain the economic impact of groundwater overuse and aquifer conservation of groundwater saving for trade.

3.3.4 Permit trading systems

The centralized market mechanism is the most common method of trading groundwater permits (Aghaie et al., 2020). In centralized markets, the bids of participants are usually matched through double auctions with two pricing systems: uniform and discriminatory second price. Purchasing and selling goods with multiple sellers and multiple buyers is called a double auction (McAfee, 1992). The central organization will select the transaction price in a uniform double auction, but bidders will determine groundwater pricing in the discriminatory second price double auction. The double auction process starts with the bidding phase, in which buyers and sellers offer their groundwater value and quantity (McCabe et al., 2018). After collecting participants' offers, the central institutions (in our case, each GMD) sort all the bids of buyers and sellers, respectively. The price paid will be the second-highest bidding price (McAfee, 1992). The bidders have different groundwater prices assuming heterogeneity, and a random selection is made if the same bid price is repeated, with priority given to the larger quantity bidder. The buyers' bids (O^b) are sorted in descending order $O^b(b_1, b_2,\cdots, b_n)$: $b_1 \geq b_2 \geq\cdots\geq b_n$ and the sellers' offers $O^s(s_1, s_2,\cdots, s_n)$: $s_1 \leq s_2 \leq\cdots\leq s_n$ are sorted in ascending order. If there is any remaining quantity after matching the first seller and the first buyer, the next buyer will take it until s_n matched pair. The permit trading process is based on a quasi-linear assumption of utility for each participant and his or her private groundwater value-based bidding system.

3.3.5 Uniform price double auction

Under the uniform price market structure, the central market institution will attempt to set the price near the equilibrium price through a double auction at an identical price. The groundwater permit price for buyer i is represented as $p_i^b = MR_i - (v(I,J) - v_{-i}(I,J))$ where MR is their own value of groundwater and $v_{-i}(I,J)$ is the indirect utility when the buyer i paid for and bought at auction. Likewise, the groundwater permit price for seller j is represented as $p_j^s = MR_j - (v_j(I,J) - v_{-j}(I,J))$ where $v_{-i}(I,J)$ is the indirect utility when the buyer j paid for and bought at auction. The market institution calculates the equilibrium price, sorts the bids again, and then obtains a new market supply and demand using the calculated equilibrium price. A market's equilibrium price is determined by the quantity demanded and supplied, so this accepted price is the equilibrium price. The equilibrium price will be set according to the new market price if the obtained equilibrium price differs from the actual equilibrium price.

3.3.6 Discriminatory second-price double auction

An individual in a second price mechanism is bidding their true value and not attempting to estimate what everyone else is going to bid. In second-price auctions, bidding true value is the dominant strategy (Kagel & Dan, 1993). The bidder will not be rewarded for deviating from the truth-telling. When the second-highest bidder has the option of increasing their bid, and they choose to do so, their new bid would exceed their initial bid. The bidder will have to pay more than their original value if they win, reducing their payoff. In addition, the bidder may decide to reduce their initial bid. As a result, individuals are not disadvantaged because they bid on the maximum amount they are willing to pay. The discriminatory second-price double auction evaluates each participant's characteristics when offering groundwater permits since they have a different groundwater value. This mechanism matches the first highest buyer with the first lowest seller by sorting the bid prices discerningly by buyers and ascendingly by sellers. This process continues until there is no supply left, all demands are met, or no buyers bid higher than sellers' bids. The central market institution arranges matching pairs to maximize participants' benefit and ensure natural ordering. This trading system provides that the allocation of groundwater permits leads to social benefit maximization. Each bidder's utility should be nonnegative, allowing permit trading to have a nonnegative payoff. We are now concerned with how much each winning seller will receive and how much each winning buyer will pay for a groundwater permit.

3.3.7 Buy-back program

The government buy-back program is supported by many studies showing its positive economic and environmental impacts (Grafton & Wheeler, 2018; Aghaie et al., 2020; Zolfagharipoor et al., 2022). The buy-back program in this study intends to lower overall issued groundwater permit caps to act as a top-down compensation-based program that benefits farmers and the environment. Specifically, we are interested in knowing how much is spent on permits that would be used in a trading scenario. When a central market institution makes a successful transaction, we assume that the authorization price is the price of the last transaction.

3.4. Simulation Results

Water trades are voluntary purchases and sales of water. In the short term, temporary water transfers have already been allocated and are available for immediate use. Water is an uncooperative commodity, which challenges those willing to trade water or help manage water use (Bakker, 2007). Because of permit trading, changes in the timing, location, and efficiency of water use matter (Young & McColl, 2009). The demand for groundwater in Kansas is primarily driven by irrigated agriculture. The groundwater wells are usually not closed, so a new irrigated area can still be developed, and new water permits will be allowed. Demand for groundwater is influenced by annual water availability and proportional allocation rules based on priority classes in Kansas. For permit trading to be successful in Kansas, it must overcome barriers to sustainable groundwater management, such as issuing new water permits each year, high non-use rates, and non-infringement of seniorities' water rights. The actual water usage rate in other areas is less than 50%, except for GMD2 and GMD5. Compared with the authorized groundwater usage, it was used very little. For example, the actual water use of GMD 1 was 12% of the authorized water permit. While natural rainfall may be impacted, the actual groundwater usage, which is lower than the licensed groundwater usage, allows revisiting for groundwater conservation policies to be reconsidered for future generations.

In our simulation, we first limited the amount of water that can be traded to a maximum of 10% of the authorized quantity of active permit farmers because of the problem of initial over allocation. In addition, to deal with unused groundwater, we set up a scenario by temporarily returning 10% of unused authorized groundwater to GMD as transaction taxation. The total number of groundwater permits issued was 18,749, and 12,591 permit holders, 67% of which are actual users, participated in permit trading and buy-back scenarios. One of the significant problems with the market is that water agencies do not always know the value of water. The agency may have to adjust the stated price until a market-clearing condition is found (Zilberman & Karina, 2005). We calculated the groundwater value of each irrigation well from the crop-water functions, and these values will be the permit transaction price. This research confirms previous findings and contributes to understanding the actual groundwater value calculation of each GMD using the crop-water production functions and WIMAS data (Table 3.2). Kansas groundwater is worth an average of $782.73 per acre-foot (Table 2.2).

Table 3.2. Groundwater Value and Estimated Revenue before Trading

	Estimated Revenue of Permit Holder			Estimated Mean of Groundwater Value (Dollars per A/F)
	Mean	Min	Max	
Total	$122,555.56	$162.82	$736,475.93	$782.73
Non GMDs	$71,072.91	$716.59	$319,942.36	$805.64
GMD 1	$83,905.88	$220.70	$349,642.03	$845.05
GMD2	$87,574.79	$2,093.04	$227,547.99	$774.35
GMD 3	$157,414.28	$2,138.17	$736,475.93	$727.70
GMD 4	$106,049.79	$1,120.99	$679,200.95	$902.08
GMD 5	$115,996.49	$162.82	$351,116.40	$737.94

The area with the highest value is GMD4 at $902, and the area with the lowest groundwater value is GMD3 at $727. An irrigation permit holder with a lower-than-average value will be more likely to gain more revenue from the selling permits than from using water to irrigate. A permit holder with a higher-than-market value will purchase more groundwater rights and invest more in crop production. Prior to groundwater trading, the GMD3 region showed an average production return of $157,414, and the Non-GMD region was calculated to be the lowest at $71,072. This is the current status quo when a groundwater trading system is not in place. Since we do not include the production cost of each groundwater holder, we expect that total revenue must be greater than the production cost. Two auction mechanisms, uniform double auction and discriminatory double auction, will be used to assess Kansas's hydrological and economic impacts based on cap-and-trade. We set the average groundwater value in each GMD as the transaction price. The marginal revenue for all wells within each GMD is equalized in this way (Montgomery, 1972). Groundwater buyers in both trading simulations pay groundwater sellers. After adding the use of purchased groundwater to the current groundwater use, groundwater buyers' additional income was calculated using the crop-water production functions. Economic benefit was computed using the pure income increase after paying for the purchase of groundwater.

The market price in the Uniform Double Auction[7] (Table 2.3) was set based on the average value of groundwater for each GMD. It costs $845 for GMD1, $774 for GMD2, $727 for GMD3, $902 for GMD4, and $737 for GMD5 (Table 2.2). Based on these market prices, 5,203 groundwater users among active users of Kansas groundwater become sellers, and 6,536 participate as buyers. Groundwater sellers generate an average of $10,772 extra income, and buyers can earn an additional $13,046 after purchasing additional groundwater rights. In terms of region, GMD3 averaged $15,267 in buyer income and $13,840 in seller income, the highest benefit among the five GMD regions. The total benefit to permit buyers is $87,176,315, and the benefit to sellers is $59,925,550 (Table 2.3).

[7] According to geographical management limitations, non-GMD permit holders were excluded from the groundwater trading simulation.

Table 3.3. Gain from Uniform Double Auction

		Number of Permits	Additional Income Increase by permit trading ($)			
			Total	Mean	min	max
Buy	Total	6,536	87,176,315.37	13,046.15	91.42	119,428.85
	GMD 1	442	4,403,786.07	10,703.58	160.11	56,416.48
	GMD2	394	3,794,204.16	10,431.55	903.51	35,259.99
	GMD 3	2,788	37,333,575.02	15,267.96	677.98	119,428.85
	GMD 4	1,529	20,216,202.55	10,531.90	91.42	109,975.67
	GMD 5	1,383	21,428,547.57	13,956.97	185.78	56,496.66
Sell	Total	5,203	59,925,550.52	10,772.16	2.21	58,288.77
	GMD 1	495	3,055,901.92	6,173.54	6.76	36,651.51
	GMD2	438	3,143,920.62	7,177.90	121.57	18,971.58
	GMD 3	2,049	33,342,008.93	13,840.60	10.92	58,288.77
	GMD 4	1,061	9,324,408.56	8788.32	90.21	44,769.33
	GMD 5	1,160	11,059,310.49	9533.89	2.21	28,275.65

In the Discriminatory Double Auction (Table 3.4) scenario, 5,875 permit holders participate as sellers, with 5,864 permits being buyers. After sorting the buyer and seller biddings, match the quantity and price to close the transaction. Sellers earned an average of $13,529 from groundwater permit sales, while buyers earned an average additional income of $10,499. Results vary across regions. GMD3 has the highest revenue gains, with sellers earning an average of $12,599 in additional income and buyers earning an average of $16,307 in additional income. Permit buyers' additional benefit is $61,564,166 and additional benefit of sellers is $79,333,835. The total additional benefit is $140,898,001 from the discriminatory second-price double auction.

Table 3.4. Gain from Discriminatory Second-Price Double Auction

		Number of Permits	Additional Income Increase by permit trading ($)			
			Total	Mean	min	max
Buy	Total	5,864	61,564,165.69	10,498.67	81.12	14300.59
	GMD 1	431	3,319,324.64	7,701.45	118.70	24,870.16
	GMD2	390	2,880,811.76	7,386.70	935.15	14,300.59
	GMD 3	2,493	31,411,369.75	12,599.82	678.85	49,276.06
	GMD 4	1,338	11,881,057.93	8,879.71	81.12	49,007.20
	GMD 5	1,212	12,071,601.61	9960.07	78.23	23,159.12
Sell	Total	5,875	79,333,834.87	13,528.96	10.05	70,152.79
	GMD 1	506	3,917,222.79	9,088.68	43.62	31,546.32
	GMD2	442	4,025,272.75	10,321.21	89.93	20,959.40
	GMD 3	2,344	40,653,665.70	16,307.13	10.05	70,152.79
	GMD 4	1,252	13,683,078.23	10,226.52	100.51	60,968.47
	GMD 5	1,331	17,054,595.39	14,071.45	109.76	33,337.54

Compared with additional total revenue, the Uniform double auction generated a more socioeconomic revenue of $6,203,864. However, producer benefit is significantly higher than $19,408,284 in Discriminatory Double Auction, and consumer benefit is $25,612,150 higher in Uniform Double Auction. As a result of buyers purchasing groundwater at a relatively low price in the Uniform double auction and putting it into production, it is judged that the total benefit is higher than the discriminatory double auction due to higher consumer benefit.

Without introducing a trading system, the government's buy-back program (Table 2.5), one of the top-down methods, was calculated to cost $132,039,137 to reduce the unused permit of 10% among active wells. The social cost of the buy-back is much higher than the two trading scenarios.

Table 3.5. Cost of Buy-Back Program

	Number of Permits	Available groundwater quantity (A/F)				Cost of Buy-Back ($)			
		Total	Mean	Min	max	Total	Mean	Min	max
Total	12,591	172,370.47	13.69	0.003	89.8	132,039,137	10,486.79	2.21	65,347.46
Non-GMD	852	6,525.87	7.66	0.06	32.53	5,257,503	6,170.78	48.34	26,211.50
GMD 1	937	7,551.97	8.06	0.08	43.37	6,381,788	6,810.87	6.76	36,651.51
GMD2	832	8,192.155	9.84	0.11	24.5	6,343,595	7,624.51	85.18	18,971.58
GMD 3	4,837	89,438.9	18.49	0.012	89.8	65,084,687	13,455.59	8.73	65,347.46
GMD 4	2,590	25,630.31	9.86	0.1	61	23,120,591	8,926.87	90.21	55,026.88
GMD 5	2,543	35,031.26	13.77	0.003	38.32	25,850,970	10,165.54	2.21	28,275.65

The unused permit may flow into the groundwater trading market, which will be used by farmers who lack agricultural water to generate revenue. In our simulations, it was found that there was an increase in farm household income in all regions. In addition, the number of permits temporarily submitted for transaction costs has increased, and the reduction of authorized quantity has significantly progressed. However, the ultimate goal of actual groundwater use reduction through water trading is not easily accomplished due to many unused authorized quantities in Kansas.

3.5 Discussions

3.5.1 Over-allocation problem

A Kansas person wishing to utilize water for a purpose other than domestic use must file an application accompanied by how much water is requested. The application may be approved if all three of the following conditions are met: (1) Water is available at the requested location; (2)

No adverse effect on other water rights, the minimum required streamflow, or the public interest will result from appropriating the water; and (3) There are no other requirements by the Division (KDA, 2021). Interestingly, although the Kansas groundwater permitting procedure is complicated, as shown in Table 2.6, much groundwater is unused after obtaining permission. In GMD1, the actual groundwater usage was only 12% of the permitted amount, and in GMD5, 70% of appropriated groundwater was used.

Table 3.6. Actual Water and Land Use

	Authorized Quantity (A/F)	Actual Water Use (A/F)	Percentage (%)	Authorized Cropland (Acres)	Actual Land Use (Acres)	Percentage (%)
Total	5,265,109	1,847,805	35	7,673,723	1,883,487	24
NonGMDs	168,736	73,603	43	255,745	80,292	31
GMD 1	618,861	76,853	12	1,017,086	114,209	11
GMD2	162,817	98,789	60	186,780	100,844	53
GMD 3	2,998,548	942,208	31	4,672,468	902,695	20
GMD 4	753,754	261,706	34	947,989	342,285	36
GMD 5	562,392	394,642	70	593,653	343,162	57

Data source: KGS WIMAS

The Kansas Water Act also deems permits regarding abandonment when a water right goes unused for five consecutive years without sufficient reason (KDA, 2021). Sufficient reasons for non-use include lack of water available from the source, natural precipitation providing adequate moisture for the cultivation of crops that would generally require irrigation, or temporary contamination of the water supply. In addition, if an area has been closed to new appropriations by rule, regulation, or order of the chief engineer, then the groundwater right is considered to have sufficient cause for non-use and is not considered abandoned.

As shown in Figure 3.4, new water permits and authorized quantities are increasing every year. Groundwater depletion of HPA is becoming an issue. If economic incentives or climatic fluctuations temporarily consume unused groundwater, this will create future problems The equilibrium permit price of permits is indeterminate due to the surplus of unused permits over the demand by constrained users (Palazzo & Brozovic, 2014). Also, if there is no institutional discussion regarding unused permits, a market-based approach to groundwater conservation may be difficult. For example, Australia instituted water markets but failed to realize the decision that this would activate unused water rights. The first cap on water usage led to the government purchasing billions of dollars worth of water entitlements in the 2000s (Wheeler et al., 2016). This has also caused many farmers to sell their unused water and, therefore, increasingly rely on groundwater releases to fuel their farm production since the demand for water permits has significantly increased (and prices are perceived to be higher). This was observed that growth in groundwater use is unsustainable in the Murray Darling Basin in Australia (Crase et al., 2004).

Our simulation follows a cap-and-trade program that has proven effective performance in the emission market over the last 40 years. Conservationists favor cap-and-trade. The cap would provide certainty about groundwater extraction's impact on the aquifer. The level of the authorized quantity determines the environmental benefit of cap-and-trade for Kansas groundwater conservation. However, the cap has not been appropriately stringent in Kansas. The overallocation problem limits our simulation. A water allocation mechanism should have desirable features similar to an economic notion of efficiency, as outlined by Howe et al. (1986). More simply, the benefit from permit trading must outweigh the economic motivation for groundwater saving.

3.5.2 Equity concerns regarding seniority

Kansas Division of Water Resource (DWR) created two classes of water appropriation rights on October 1, 1965. Junior permits are issued after October 1, 1965, while Senior permits are issued before that date. The junior permit holder has many more pumping restrictions than the senior permit holder (Peck et al., 2019). However, these water rights holders in the more junior group were cut in the same percentage, not according to strict priority. Water users do not want their water to be cut off without their consent. However, under the current system, when junior and senior have conflicts regarding groundwater use, Senior is given priority.

During times of increased groundwater demand, it is essential to quantify the specific groundwater permits held by particular individuals. It is expected that junior holders, the majority of groundwater irrigation permit holders in Kansas, will suffer economic damage. Furthermore, voluntary techniques are seldom effective (Livingstone & Garrido, 2004). Nearly 20% of the current water permit holders registered with WIMAS had a permit issued before October 1, 1965. Table 2.7 indicates that senior water holders obtained more authorized quantity and authorized cropland permits but used less actual water use and actual land use than junior water holders. On average, seniors were permitted 353 acre-feet, which is about 100 acre-feet more than juniors. However, the seniors' actual usage was about 20 acre-foot less than that of junior holders.

Table 3.7. Groundwater Seniority

		Mean Authorized Quantity(A/F)	Mean Actual Water Use (A/F)	Mean Authorized Cropland (Acres)	Mean Actual Land Use (Acres)
Total	Junior	248.6	101.3	385.0	101.3
	Senior	353.6	80.6	449.1	92.9
Non-GMDs	Junior	118.6	49.8	181.5	55.8
	Senior	129.3	44.5	170.6	49.0
GMD1	Junior	257.6	38.1	497.6	56.0
	Senior	370.5	32.6	466.3	50.0
GMD2	Junior	124.9	68.7	137.4	71.6
	Senior	118.3	58.4	151.4	66.5
GMD3	Junior	344.2	118.6	573.3	110.6
	Senior	462.4	92.1	568.8	102.3
GMD4	Junior	238.9	84.3	304.6	110.6
	Senior	284.2	82.3	321.9	108.5
GMD5	Junior	167.5	115.2	172.8	101.0
	Senior	191.6	87.2	203.0	86.0

Data source: KGS WIMAS

Water policy's economic efficiency is generally criticized because it is concerned with the degree of benefits, not the distribution (Young, 2010). Some equity concerns could be addressed by carefully applying the efficiency criterion to the market transfer policy. Water rights are redistributed through free transfers between buyers and sellers in the permit trading system. The distributional effects of market processes are determined by the status quo allocation of water rights. Markets require the initial assignment of permit rights in groundwater to provide the starting point. Senior water holders always have an advantage over junior water holders when it comes to groundwater use in Kansas. By incorporating third-party impacts such as the negative impact of neighbors' groundwater use, groundwater flow, and quantity considerations into market decisions, the Kansas legislation system should protect the interests of seniority in the market when senior water holders claim. The problem with such enforcement is that it is costly and could impede transactions. Water flows and quantity changes in groundwater are more complicated to value than water used in consumptive irrigation. This results in information imbalances and a trend to promote water uses with easily documented values.

3.6 Conclusion

It is undeniable that extraction over recharge is not sustainable. The depletion of the High Plains Aquifer as a water source will severely affect Kansas' agricultural productivity and the overall economy. The location and type of irrigation will change as the HPA depletes. All irrigation operators in the High Plains need to adopt sustainable practices that can provide economic and societal benefits while protecting future generations' access to groundwater.

It is commonly argued that using market mechanisms will lead to a shift in behavior. These results can be easily confirmed in the case of Australia, where permit trading is active (Wheeler et al., 2013). Based on the existing studies, it is clear that farmers prefer the water markets and are getting closer to a situation where water use or sales are based on a rational analysis of water market prices and crop prices.

The results in our study support the claim that the market-based approach has limitations in Kansas. Key findings emerge from the short review above regarding overallocation, equity concerns, and actual groundwater value. We describe the result of overallocation, which shows the instability of market clearing conditions. It is suggested that a new policy on dormant water permits is required to do rights of groundwater users. In light of our simulation of the trading of groundwater permits in Kansas, we may show a more general warning. Water conservation may seem less urgent due to the significant disparity between authorized and actual groundwater use. This confirms previous findings in the literature (Young, 1986); when water is abundant and relative demand is low, water laws tend to be simple and rarely enforced. The problem is that Kansas has insufficient groundwater, but authorized use is much more than actual use. States that rely on HPA, including Kansas, are facing groundwater depletion and have no time to delay conserving groundwater for future generations, but it is not easy to preserve groundwater without adverse economic effects. As a result of political and legal obstacles, the top-down approach by the state has limitations, and the bottom-up approach by the agreement of groundwater users requires a great deal of time due to conflicts of interest. The market-based approach could promote sustainable groundwater use under the current Kansas groundwater use trend, providing more returns to farmers with higher yields.

We estimate a marginal monetary value for each GMD's groundwater. Kansas has an average marginal value of groundwater of $782 per acre-foot. The GMD4 region has the highest estimated value at $902, and the GMD3 area is the lowest, at $727. Based on these calculated values, the market-based approach also increased the private net benefit, as sellers and buyers of permits are better off after trading. However, relative benefits to buyers and sellers depend on the trading system assumed. Buyers made $27,250,765 more in Uniform Double Auctions, while the sellers made $17,769,669 more in Discriminatory Double Auctions.

The simulation of groundwater trade and mandatory return of unused groundwater rights showed that it is possible to reduce the total amount of issued groundwater quantity by increasing the economic benefits for groundwater users. However, one might question whether the social net benefit has increased. If unused permits flow into the market, it is simply pulling future income to the present from the future.

Although we did not model the dynamic effects of permit trading on groundwater, our results showed that groundwater use could be reduced when permit trading and the return of unused groundwater rights are combined. Given the current situation of overallocation in Kansas, the impacts of a market-based trading system may be limited. However, as conditions change, a market for trading water rights could be more beneficial.

Chapter 4

Conclusion

The purpose of this concluding chapter is to summarize and discuss the contribution of the key research findings from the dissertation. A review of the limitations of the study will also be presented, along with suggestions for future research.

Essay 1 examined the impact of climate stress and water quality on beef cattle production in terms of yield index and marbling score. We first observed that the yield index worsened in response to cold or heat stress. Stress caused by heat and cold also negatively impacted marbling scores. According to the simulation analysis, exposure to weather stress steadily increased producers' losses. Weather risk management in beef cattle production is essential to mitigate producers' losses caused by severe weather conditions. Existing strategies include modifying land use, animal feeding, genetic manipulation, and changing species and breeds. These strategies, alone, might not be enough to cover producers' financial losses due to extreme weather events. Weather index-based beef cattle insurance is another potential tool to mitigate the potential losses caused by extreme weather events. Secondly, we observed that water affects physiological processes in beef cattle directly or indirectly. By supplying weak alkalinity substances to the feedlot, we found that our pH had a good effect on the performance of beef carcasses. Analyzing the water content is relatively straightforward, but our estimation results with extreme weather may need to be approached with caution.

There may be limitations to our research. Firstly, all carcass data were collected at a single location. This means that common regional adaptations to weather stress (e.g., breed selection) likely do not vary widely across feedlots. In addition, although travel time affects yield grade slightly, the average transport time is approximately four hours and does not vary significantly among our samples. Even though we used some water quality data for estimation, long-term observation is necessary to determine its exact effect on beef carcasses. In addition, more observational data are needed to control the surrounding environment rather than the weather to control water intake in response to changes in the external environment. A follow-up study is necessary to determine how water quality affects beef cattle performance after calves.

In essay 2, we confirmed that it is undeniable that extraction over recharge is not sustainable. It is imperative that irrigation operators in the High Plains adopt even more sustainable practices in order to provide economic and societal benefits without adversely affecting future generations' groundwater resources. The simulation of groundwater trade and mandatory return of unused groundwater rights showed that it is possible to reduce the total amount of issued groundwater quantity by increasing the economic benefits of groundwater users and acting as an intrinsic incentive. We derive a monetary value for the groundwater of each GMD. Based on these calculated values, the market-based approach was also shown to increase the private net benefit. However, one might question whether the social net benefit has increased. If an overused permit flows into the market, it is simply pulling future income to the present from the future.

The results of our study support the claim that the market-based approach has limitations in Kansas. Key findings emerge from the short review above regarding overallocation, equity concerns, and actual groundwater value. We describe the result of overallocation, which shows the instability of market clearing conditions. It is suggested that a new policy on dormant water permits is required to do rights of groundwater users. Although we did not model the dynamic effects of permit trading on groundwater, our results showed that when permit trading and the return of unused groundwater rights are combined, the permitted groundwater use could be reduced.

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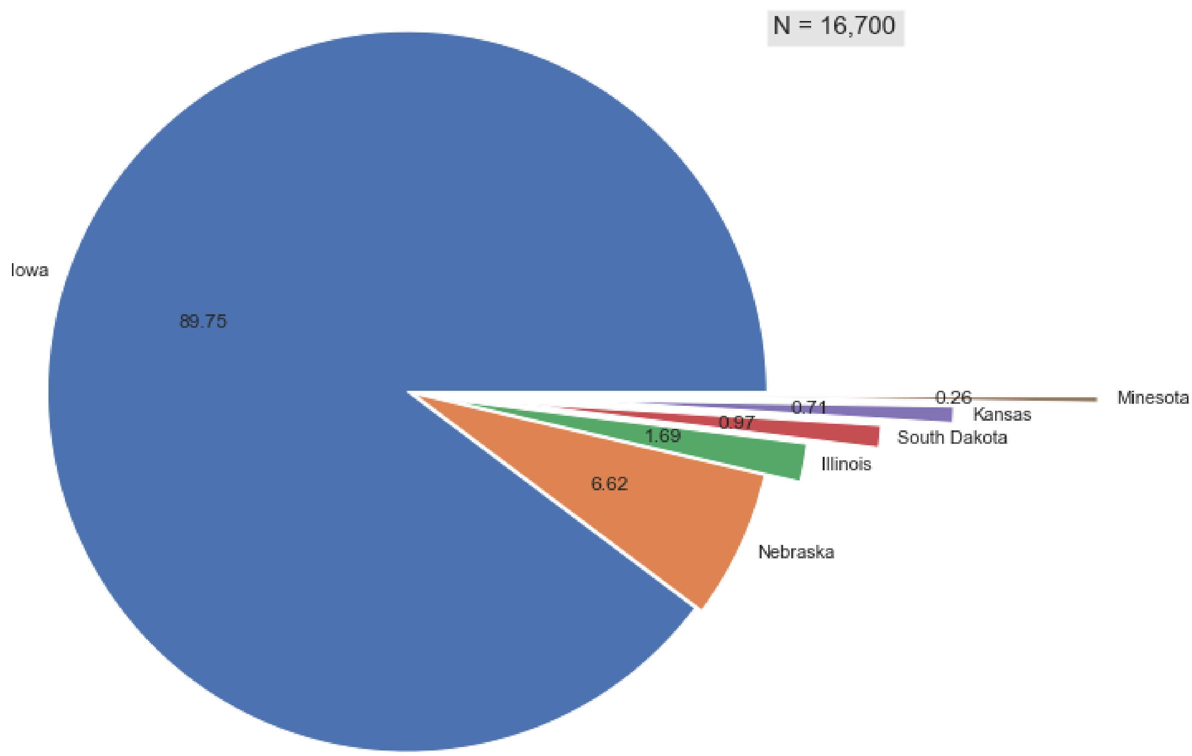
Appendix A

Appendix to Chapter 2

Figure A.1. The Percentage of Processed Beef Cattle by State-level

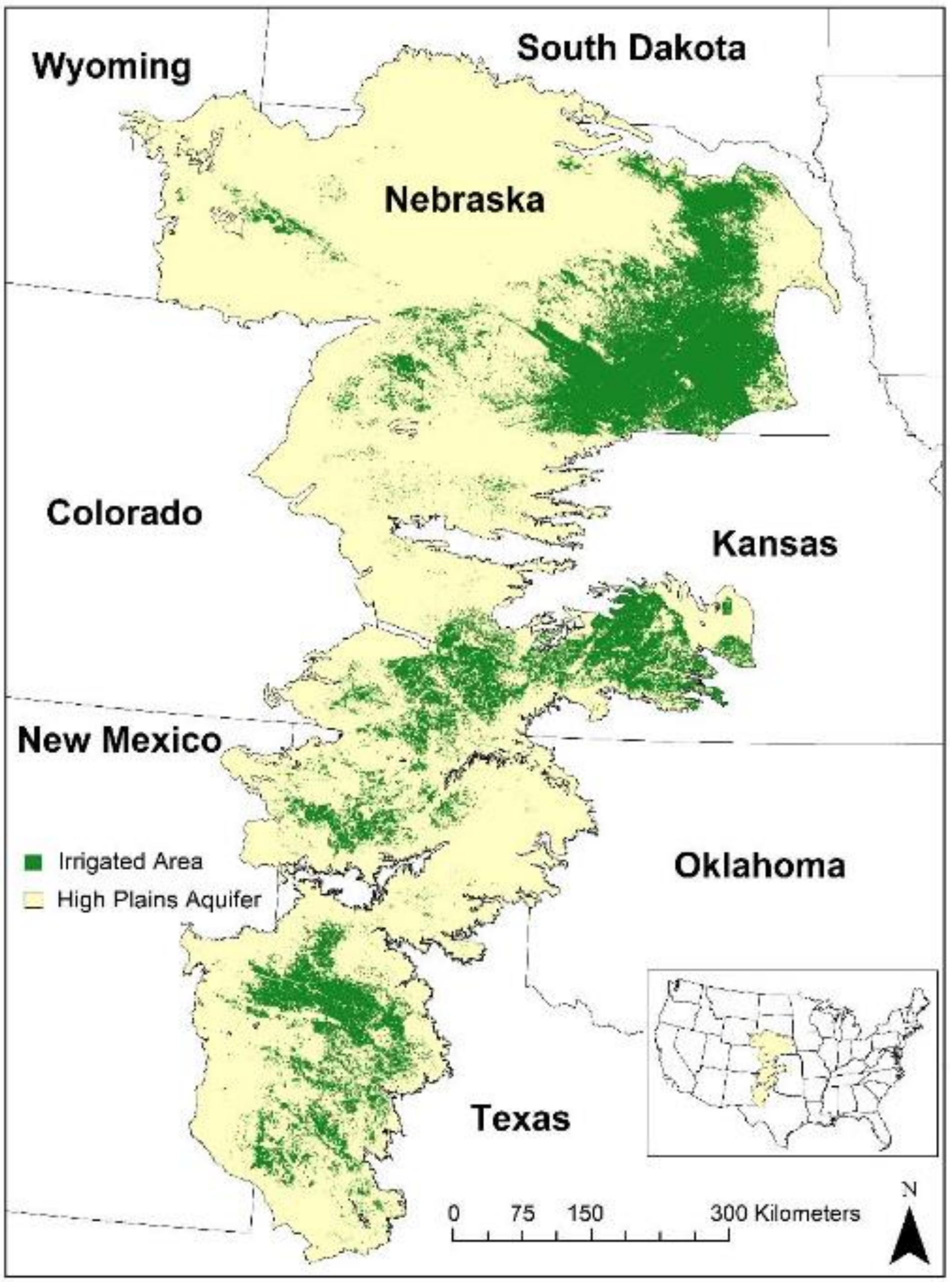


Source: The figure is the author's calculations from midwest plant carcass data.

Appendix B

Appendix to Chapter 3

Figure B.1. The Expansion of Irrigated Areas over the High Plains Aquifer (HPA) in the United States



Source: Salmon et al. (2015)