LAND VALUES AND CLIMATE CHANGE:

HOW, AND TO WHAT EXTENT, DOES CLIMATE CHANGE AND DESERTIFICATION IMPACT AGRICULTURAL LAND VALUES?

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Abstract

According to most 'climate scientists', an increase in temperature will be seen in the 21st century due to emission of greenhouse gasses by human activities. This thesis does assess the impact of an increase in temperature on agricultural rents and land values. Earlier studies showed that an increase in temperature will severely impact agricultural production. In this master thesis which performed a case study on Kansas corn production, it was found that an increase in temperature negatively impacts corn production significant, with a decrease of production up to 55% if temperature increases by 4 degrees Celsius. A second analysis in which the impact of decreasing production on rents was estimated, showed that rents for agricultural land in the US can go down by 63% if temperature increases by 4 degrees Celsius. This thesis proposes a refined model which estimates the impact of temperature increase on agricultural rent and land values concisely as a tool for future scientific elaboration of this important topic.

Keywords: agricultural real estate, agricultural economics, climate change, global food security

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1. INTRODUCTION

1.1 Motivation

Only 11% of the global land surface is suitable for agricultural production. This land surface has to produce food for all 7.5 billion worlds' inhabitants, a population which is expected to increase even further in the coming decades. Due to changing weather and geological processes in many agricultural areas, production capacity of agricultural land is under pressure. Such changes in weather and geological conditions can be of different sorts. A key change is that 33% of the global land surface (both agricultural and non-agricultural) is to some extend threatened by desertification, a process in which a combination of increasing temperatures, a decrease in (predictability and reliability of) rainfall and erosion decreases the production capacity and fertility of agricultural land and increases the volatility in agricultural yields (Eswaran et al., 2001). The effect of such climate change and soil erosion is not only present in the developing countries. In 2017 a (sharp) decrease of land values in the Central Californian Valley, one of the most prominent agricultural region's in the US for growing vegetables, fruits and nuts, was reported (The Sacramento Bee, 2017). According to Rabobank economists this was due to a combination of falling commodity prices and ongoing drought which decreased agricultural production and increased agricultural yield volatility. Areas with big shortages in water supplies (not only rainfall but also shortages in irrigation resources such as rivers, reservoirs and ground water) saw a sharper decrease land values (The Sacramento Bee, 2017).

Decreasing yields and increasing yield volatility (e.g., increase in risk) can be problematic for both farmers and landowners. For farmers it implies a decreasing production level and a higher uncertainty (risk) in the volume of their production, and thus a bigger financial risk. For landowners it may imply falling rents and a decline in their asset value. But not only farmers are affected, also stakeholders which are indirectly linked to agricultural can be affected. Financers (banks) and agricultural insurance companies might also be impacted by the effect of changing weather patterns on agricultural land (values). In the end the problem of a potential decrease in agricultural yields and an increase in yield volatility might affect everyone; in combination with the growing demand for food by an increasing human and livestock population, it can increase the risk of temporary shortages in food supply.

Decreasing land values are in theory an obvious consequence of decreasing agricultural yields and increasing yield volatility. However, extensive and robust quantitative proof is absent, also in the case of yield volatility. Not in the last place since in general advancing agricultural technology caused a gradual increase of yields and a decrease of yield volatility throughout history. The aim of this thesis is to address the impact of temperature increase and agricultural yield volatility on agricultural asset values. The results of this thesis can contribute to the understanding of agricultural stakeholders of the impact climate change may have on agricultural production and agricultural assets.

1.2 Research aim

The research aim of this study is to assess weather, and how, global warming and agricultural yield volatility increase will impact agricultural asset values. This will contribute to the understanding of how climate change can impact agriculture and agricultural stakeholders. The following research questions will be answered to fulfill the research aim:

1. How, and to what extent, does temperature increase impact agricultural yields?
2. Can an estimation of the total possible loss (value at risk) on agricultural assets due to climate change be made for an area vulnerable to desertification?
3. How does increasing yield volatility impact agricultural asset values?

These research questions will be answered by a quantitative approach: by using an American dataset with various agricultural and economic indicators. As will be seen in the literature review, the effect of global warming on crop yields can be ambiguous across different climatological zones, for different type of crops and is impacted by other exogenous factors such as rainfall and wind, but also by advancing agricultural technology such as genetic modification. Since it is extremely hard to make an estimation which keeps in mind the possible future impact of all these exogenous variables, the quantitative research will be done in a case study format, focusing on Kansas in the US.

2. LITERATURE REVIEW AND THEORY

2.1 Implications of climate change for agriculture

It is well documented that increasing levels of carbon dioxide and other greenhouse gasses are likely to change future climates across the planet (Challinor et al., 2014). The exact impact and magnitude of these changes are however extremely hard to predict in a precise and concise way and are still a big point of discussion amongst scientists. Also the development of policy to counter and/or adapt (to) these changes is a major issue of debate amongst scientists, politicians and in the wider public (IPCC, 2014). The effects of climate change on the agricultural sector will however for sure not be uniform across continents, within continents and even within countries (Mendelshon et al, 1994). In, for example, South Africa an increase in temperature of 2°C is expected to lead to an ambiguous effect on agricultural production amongst different regions (Gbetibouo and Hassan, 2005). Gbetibouo and Hassan found that some South-African regions actually might benefit for climate change, whilst others might face a loss in revenue. These findings are in accordance with the findings of Mendehlson (2018), who argues that especially the lower latitude agricultural area's might suffer from a loss in agricultural revenue due to climate change, whilst some higher latitude area's might actually face increases in productivity due to more optimal growing temperatures.

To address the impact of climate change on asset value, first the impact on agricultural yields needs to be addressed. Crops have an optimal growing temperature. This temperature is different for each crop. Therefore different types of crops are grown in different climatological zones. If the temperature at a certain point in the growing season is below or above the optimal temperature this affects the production in a certain growing season. For corn, which will be the main crop of interest in this thesis, temperatures of 25°C are optimal, temperatures above 30°C are very harmful and reduce yields strongly (Schlenker&Roberts, 2006). The distribution of expected corn yield on bases of temperature is therefore skewed to the left. The problem of increasing temperatures is clearly visualized in figure 1. High temperatures beyond the optimum are growing in harmfulness (Δ becomes larger). This not only leads to a decrease in yields, but also to an increase in yield volatility (Tichgelaar et al., 2018). Tichgelaar et al. used inputs from previous studies to estimate the decrease in yields and increase in yield volatility for the major maize-producing areas in the world. In their study the effect on production and variability of a 2°C and a 4°C was tested. They take the average corn yield in the United States, which is currently at 10.46 tons per hectare. In

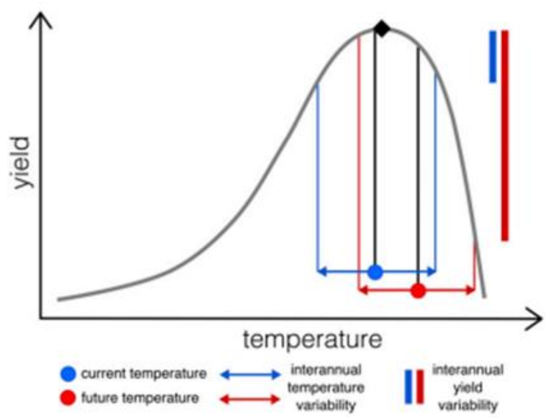

Figure 1; effect of shift in temperature on maize yields in areas which are currently highly productive. Source: Tichgelaar et als (2018) the case of a 2°C and a 4°C increase in average temperature, This yield is expected to decrease by respectively 15% and 41%. The most important output estimates obtained by Tichelaar et al. are shown in table 1.

Table 1. Estimated effect of 2°C and 4°C increase of average temperature on U.S. maize yield and U.S. maize yield volatility. Derived from Tichgelaar et all. (2018).

ΔT (°C)	mean yield (ton/ha)			standard dev. (ton/ha)			yield volatility (%)		
confid.	**5%**	**mean**	**95%**	**5%**	**mean**	**95%**	**5%**	**mean**	**95%**
present	10,45	10,46	10,47	0,51	0,52	0,54	4,87%	4,97%	5,17%
+2	8,83	8,88	8,93	0,92	0,94	0,96	10,41%	10,59%	10,75%
+4	5,89	6,01	6,14	1,22	1,25	1,28	19,86%	20,80%	21,73%

As can be seen from table 1, a 2°C increase would more than double the volatility in U.S. maize yields, a 4°C increase would increase yield volatility by more than 4 times. This study only takes the change in average temperature into account. Other factors such as changes in precipitation and wind were not reckoned with. Precipitation is however for most of the investigated area's slightly negative correlated with average temperature, and therefore the authors expect that the change in precipitation due to climate change will strengthen the decline in production and increase in volatility even more in the case of an increase in average temperature. Furthermore, the figures in the above presented table are nationwide averages. For area's which are currently already relatively dry and hot, the effect might be (much) stronger. The authors however also mention that heat tolerant, genetically modified maize can provide (partly) a solution to increasing temperatures. Until now only small successes are made in the development of such heat tolerant maize plants. Genetically modified maize also experiences a lot of resistance from the public opinion because of its risks for human health and the global ecosystem are not fully known (Tichelaar et al, 2018).

2.2 Asset pricing: risk versus return

Return is inseparable related to risk. A higher expected return requires under normal asset pricing markets a higher related risk (Jensen, 1969). Many theories try to explain how risk is related with return, which 'amount' of risk is acceptable for a certain return, or in other words; which return is required for a certain amount of risk. Under normal market conditions the discount rate which is applied to discount future cash flows of an investment is equal to:

$$(1)\quad r_s = r_f + (risk\ premium\ for\ investment\ s)$$

In which r_s is applied discount rate for an investment and r_f the risk free rate (Berk&DeMarzo, 2011). Since risk is to some extent inherent to agricultural production, one can expect that the required return/discount rate of agricultural production lays above the risk free rate. Therefore cash flow generated by agricultural assets such as land or a rental contract (see 2.3) are expected to be discounted for this extra risk, and thus have a risk premium. Land with a high volatility in agricultural production and thus a higher volatility in generated cash flows is expected to be more risky and therefore is expected to generate a higher return. The expected return of a cash flow can be calculated by the distribution of probabilities, which can be calculated as follows:

$$(2)\quad Expected\ return = E[R] = \sum_R P_R * R$$

In which is R is the occurrence of a certain return, and P_R is the probability of this occurrence. Next, this expected cash flow should be discounted for the expected/applied risk. See hypothesis (2.7) how this is expected to impact rent levels in agriculture.

2.3 Asset pricing in agriculture

Land which is suitable for agricultural production has value for its owner; being the owner of such a plot of land gives the opportunity and exclusive right to produce products with a possible economic value. As owner of such a plot of land you also have the opportunity to rent this land out to a lessee. In this case the lessee temporary takes over the opportunity and rights to produce products, but also takes over the risk and possible return which are inherent to the agricultural production process. The value of agricultural land for an owner therefore is equal to:

$$(3)\quad P_0 = \sum_{t=1}^{\infty} R_t\,/(1+r_s)^t$$

In which P_0 is the value of land at present, R_t is the rental value of land, and r the time specific fixed discount rate. This thesis mainly focused on land value (P) due to the effect that volatility of agricultural revenue has on the rent of land (R). It might be intuitive to assume that volatility in agricultural revenue also might impact the discount rate. This is assumable however not the case in the equation 3, and would only be the case if agricultural revenues would be directly discounted, for example by a farmer which both owns a plot and produces on a plot. In the equation 3 therefore it would be at a specific point in time equal amongst different plots, under the assumption that a change in rental income (for example due to climate change) isn't expected. Otherwise the equation would be written as each years' rental income separately discounted. In the case of a lessor/lessee situation the risk of potential revenue volatility is due to the lessee and therefore anticipated on by the lessee due to the rental price which this lessee is willing to pay. In the case of a landowner which produces agricultural products by own means and bears the risk of this production, the capitalization of agricultural land would be equal to:

$$(4)\quad P_0 = \sum_{t=1}^{\infty} S_t\,/(1+r)^t$$

In which S_t is the average revenue. Revenue volatility would be anticipated by differences in the discount rate r. Again, this equation only holds in case that the *average* long term yield is not expected to change. In accordance to the previous two equations, it can be obtained that the market for agricultural land, everything else equal and no non-agricultural inputs for land value and/or rental prices accounted for should be in equilibrium by:

$$(5)\quad \sum_{t=1}^{\infty} S_t/(1+r)^t = \sum_{t=1}^{\infty} R_t/(1+r_f)^t$$

A previous case study on the Illinois agricultural land market indicated a R^2 of >0,9 in a regression of rental prices on production capacity and anticipation indicators (controlling for anticipation lags) on land values (Burt, 1986). See also section 2.4.

2.4 Rent pricing in agriculture

The rent of farmland can be seen as an asset; renting a certain plot of farmland gives the right to (freely) use that plot to produce agricultural products. Income uncertainty is however inherent to agricultural production; there are a lot of factors that can impact the economic return of agricultural production. Such factors are for example; fluctuations in commodity prices, yield volatility due to weather circumstances, fluctuations in production costs et cetera. Renting agricultural land therefore has some degree of riskiness in itself. The discussion about the formation of agricultural rent prices in the 'rent market' is centuries old. One of the first well known economists that tried to grasp the way agricultural rent levels are formed in the market was Adam Smith. In his famous book The Wealth of Nations he stated:

"Rent, considered as the price paid for the use of land, is naturally the highest which the tenant can afford to pay in the actual circumstances of the land. In adjusting the terms of the lease, the landlord endeavours to leave him no greater share of the produce than what is sufficient to keep up the stock from which he furnishes the seed, pays the labour, and purchases and maintains the cattle and other instruments of husbandry, together with the ordinary profits of farming stock in the neighbourhood. This is evidently the smallest share with which the tenant can content himself without being a loser, and the landlord seldom means to leave him anymore." ~ Adam Smith, The Wealth of Nations (1783), Chapter XI, Section I; Of the Rent of Land.

According to Smith's view, the economic gain of agricultural production by a tenant (lessee) of agricultural land, is (almost) fully obtained by the landowner, having a sort of monopoly on the distribution of land available for rent. This theory was to a large extend supported and used as a basis for the later theories of Malthus and Riccardo.

Von Thünen developed in the nineteenth century the principle of bid rent curves. He stated that the type of agricultural product which is grown some piece of land is dependent on the economic production value and transportation costs of a certain agricultural product. Later on this theory was broadened and redefined. Alonso (1960) stated that this bid rent curve does not only exists in agriculture but can explain land use in general. Each piece of land is used in its most valuable way, dependent on the value (rent) that is created and the cost of transportation (need of a central location) to the center point, which could be for example a market place, city center or central business district. According to Von Thünen, the rent level of a plot could be described in accordance with the equation:

$$(6) \quad L = Y(p - c) - Y(D * F)$$

In which L represents the rent of a certain plot, Y the physical yield of plot, p the economic production of plot, c the production costs, D the distance to the market place and F the transportation costs. This implies that the rent of two similar plots but with a different distance to the 'market place' would have a different rent. Furthermore it would imply that products which have relative less transportation costs are produced relatively further from the 'market place'. Of course since the 19th century, and also the 1960s, the cost of transportation of goods, people et cetera have gone down. Price discrepancy of similar products due to transportation costs however still exist, as can be seen in paragraph 4.7.

2.5 Other factors impacting farmland assets

Next to production (volatility) more factors might play a role in farmland asset pricing. Think for example of possible speculation on development of other types of real estate in high population density agricultural areas. As we have seen under 2.4, according to the theory of von Thünen, plots of agricultural land closer to cities, should have a relative higher value and rent compared to plots in more rural areas. To control for this, population density is added as a variable in the regression model with regard to the effects of yield volatility. See section 4.12.

2.6 Depletion of irrigation sources and the aligned risk at value for agricultural land

28% of the total surface area in use as cropland in the U.S. is irrigated. However, this 28% of land produces nearly half of the value of US crop production (USDA, 2019). Irrigation mainly takes place via the use of groundwater resources or surface water resources such as rivers and lakes. Irrigation of cropland and pastureland accounts for more than 80% of the total US consumptive water use, where in some states it accounts for more than 90% of the total consumptive water use.

In the period 2007-2012 a shrinkage of 1.2% of the total cropland surface that is irrigated was reported, while the total area used as cropland is steadily growing each year at a rate around 0.1%. In some states however, shrinkage of the total irrigated cropland surface of over 10% was reported, such as in Texas, Oklahoma, Colorado and New Mexico. (USDA, 2019) This is partly due to the fact that some regions suffer from depletion of ground water resources. The biggest aquifer (ground water system) in the US, the Ogallala Aquifer, is found to be near depletion in some parts. This underground water systems serves around 20% of the total US irrigated land. A recent estimation of the total economic value for agricultural real estate of this underground water system reported a value of $10 billion in 2002, however dropping from a its peak of nearly $25 billion in the 1960's. This value was calculated as the premium that land which can be irrigated by aquifer water system has over nearby land that can't be irrigated (Hornbeck&Keskin, 2014).

This demonstrates an extra risk aligned with land values in dryer climates; if water resources somehow deplete, the production level and yield volatility of a, former, irrigated plot will fall back to that of unirrigated land. Especially in dryer climates this means assumedly a significant lower production level and higher volatility. Combined with the expectation that a rise in temperature causes yields to go down further and causes volatility to grow, the impact on land value of a combination of groundwater depletion and a rise in temperatures is likely to be severe.

2.7 Hypothesis

To answer the research questions given under 1.2, two quantitative analysis will conducted, to answer all research questions. Firstly, a case study will be performed on the effect of increasing temperatures on crop production and land values in an arid area, and secondly the impact of increasing yield volatility will be assessed.

With regard to the findings of Schlecker&Roberts (2006) and Tichgelaar et al (2018), climate change and specifically a rise in temperatures can be harmful for crop growth due to the effect of heath damage. Intuitively, an increase in temperature will cause the most severe production losses in area's which are already relatively hot and dry. To test if the findings of Schlecker&Roberts (2006) and Tichgelaar et al (2018) can be reproduced and might vary (e.g. be larger) for area's which are already relatively hot, a case study on maize production in Kansas will be performed. Kansas is located on the southern border of the most important maize producing area in the United States. It is expected that maize production in Kansas therefore will be affected more than the U.S. average. With use of this estimation, also a prediction on possible change in land values (value at risk) can be derived.

As stated under section 2.2, the expected return on an investment is determined by the probability distribution of the occurrence of a certain level of cash flows. Furthermore the required return/discount rate of future cash flow is determined by the expected volatility (probability distribution (see figure 2)) of this cash flow. If two cash flows have the same expected average return, but cash flow 1 has a lower expected volatility than cash flow 2, this will under normal asset market conditions to a fiercer discount of cash flow 2. See figure 2 for an example of plots with a similar expected average yield (return) but different yield volatility

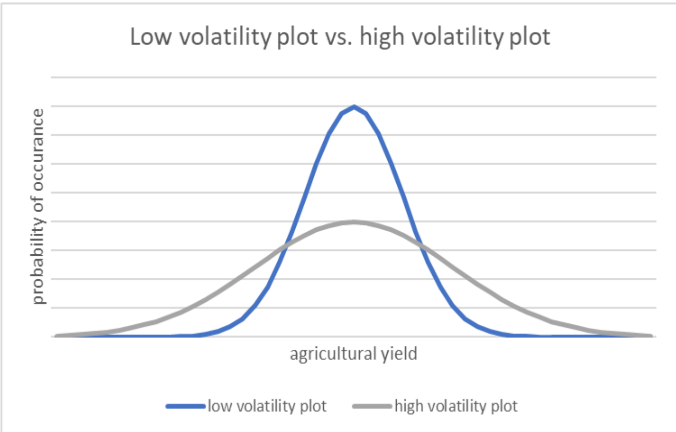

Figure 2: Graphical display of the probability distribution of plots with a similar average expected return but a difference in yield distribution.

expectations. Agricultural rent can be seen as the purchase of an asset which produces a future cash flow. It is expected that rent of land with a higher volatility in agricultural production is relatively 'cheaper', since its future cash flow is discounted 'harder'. Therefor the hypothesis of this thesis with regard to yield volatility is "agricultural rent of land is significantly negatively impacted by a higher volatility of agricultural production of this land, everything else equal".

The following hypotheses are therefore formulated:

1. How, and to what extent, does temperature increase impact agricultural yields?
   It is expected that an increase in temperature on average causes a significant loss in agricultural production. It is expected that this effect is more severe in semi-arid areas. It is expected that the decrease in corn yields in the case study on Kansas corn yields is above the estimated decrease by Tichgelaar et al (2018).

2. Can an estimation of the total possible loss (value at risk) on agricultural real estate assets due to climate change be given?
   With use of the estimation of the significant effect of temperature increase on agricultural production an estimation of the total risk at value can be given. It is expected that this risk at value tends to be rather high, both relatively and absolute.

3. How does increasing yield volatility impact agricultural real estate asset values?
   It is expected that an increase in yield volatility negatively impacts agricultural asset values. It is expected that with a production decrease, rent and thus asset values tend to decrease relatively stronger than production itself, due to the effect of production costs remaining equal.

3. METHODOLOGY

3.1 Effects of temperature on agricultural production

To answer research question 1 and 2, a case study on the effect of high temperatures on Kansas corn yields will be performed. In this case study, weather data and data on agricultural yields in Kansas for the period 1980-2017 will be exploited to discover if there is a significant causal relation between high temperatures and lower corn yields, as Schlecker&Roberts (2006) and Tichelaar et al (2018) suggested in their work.

A linear panel data regression will be performed to test for the effect of high temperatures on corn yields. Formally this regression analysis will have the following format:

$$(7)\quad Y_{i,t} = a + \sum bf_{i,t} \quad + \varepsilon_{i,t}$$

In this regression format Y constitutes the corn yield at a specific year (t) in a specific agricultural district (i) of Kansas, see also chapter 4. a Is the constant in this linear regression, $\sum bf_{i,t}$ is a set of temperature variables, which are the main independent variables in this regression and ε represents the error term. A 'Hausmann-test' will be performed to check if the error term varies stochastically over i and/or t, or not, to determine if a the panel data regression should be performed with fixed effects or random effects.

If a significant linear causal relation between yields and temperature is found, this also allows to check what the impact of an increase of temperature would have on the Kansas maize yields. As described by the work of Burt (1986) (see 2.3), the production capacity of a certain plot and the rent for this specific plot are heavily related. A significant change in agricultural yields due to a rise in temperature therefore also allows us to estimate the effect this has on land values.

3.2 Effects of increasing yield volatility

Another effect of increasing temperatures, next to a decline in agricultural yields, is the increase of yield volatility, as explained in sections 2.1 till 2.3. To see if there is any relation between yield volatility and agricultural rents, a case study to yield volatility and rents in the US 'Corn Belt' region will be performed (see chapter 4 for further explanation). A hedonic pricing model in the following conceptual form will exploited:

$$(8)\quad R = a + \beta_1 x + \beta_2 y + \sum \beta_n z + \varepsilon$$

In which R represents agricultural rent, a a constant, x yield volatility, w agricultural yield, z a set of other (control) variables that might impact agricultural rents, β the parameters of x, y and z, and ε the noise term. If both the effect of higher temperatures on agricultural yields and the effect of yield volatility on agricultural rents tend to be significant, this also would allow us to say something on the combined impact of decreasing yields and increasing volatility on land values. This would be possible by implementing the findings of the first case study in the second regression model.

4. DATA ANALYSIS

4.1 Origin of data

Most data use d in this thesis originates from the "Quickstat" database, issued by the National Agricultural Statistics Service (NASS). The NASS is an American non-profit, governmental organization, which is part of the United States Department of Agriculture (USDA). The NASS Quickstat database is publicly available and contains data about a very wide range of subjects concerning agriculture, agricultural economics, agricultural population et cetera. In total there are over 35 million data points included in the database, on various grids such as on national level, on state level, and on country level et cetera, and ranging in time from 1867 to 2018. In the next paragraphs, the variables extracted from this database will be described, along with descriptive statistics about the data.

Weather data used in the case study of the effect of heat damage on crops originates from the National Centre for Environmental Information (NCEI) public available dataset, which is published and maintained by the National Oceanic and Atmospheric Administration (NOAA). The NOAA is a publicly funded organization and the main administrator and publisher of US weather data and environmental information. The database offers data on a wide variety of topics, time intervals and location grids.

Furthermore data on population figures is used as a control variable in the second analysis on yield volatility. This data is obtained from United States Census Bureau. This dataset concerns the latest US census ('head count'), which takes place every decade, and was executed in 2010 for the last time. The grid used in this thesis, agricultural districts, is a subdivision of land area which is only used by the USDA NASS. Therefore census data on this level was not available. To solve this issue, census data of all counties in the US was downloaded and county-level data was merged manually to the level of agricultural districts.

4.2 Used units of measurement

Due to the fact this thesis solely focusses on the United States and US data, the used units of account and measurement are also based on U.S. Standards. A specific measurement unit used in thesis, and lesser known in countries which use the metric system, is Bushel (Bu). A bushel is a measurement of volume, but due to the fact that agricultural bulk products are standardized on moisture level (also to be able to trade them in international commodity markets), actually this volume can also be expressed in weight. A bushel of corn is equal to 25.4 kilograms.

4.3 Case study, heat damage on corn in Kansas: area of interest

As stated in 2.1, the relation between corn growth (and thus yield) is not linear, when temperature is low, an increase in temperature tends to have a positive effect on yields, but when temperature is high a further increase declines the productivity. Even a certain high temperature does not always do the same damage to a crop, this effect can differ due to other factors which might dampen or aggravate the impact of a high temperatures. Such factors might be for example soil moisture, air moisture, soil type, sun hours, sun intensity, latitude and the slope of a plot (Tichgelaar et al, 2018.) These factors are hard to control for, in particular when running a regression on a yearly yield rather than daily plant growth.

To overcome this issue, an area which is in general relatively heterogeneous in de before mentioned other factors is chosen; Kansas. Kansas has relatively good comparable growing conditions, homogenous soil types and not much elevation (USDA, 2018). Furthermore, the NASS has specific data available for Kansas which differentiates between irrigated and non-irrigated land, and weather data for Kansas is abundant. Kansas can also be seen as the 'southern border' of the main production area of corn in the US (see also 4.8.) and is known to have severe problems with drought, increasing temperatures and shrinking water supplies (Hornbeck&Keskin, 2014). It is therefore a good proxy to study the effect of increasing temperature on crop yields.

4.4 Case study, heat damage on corn in Kansas: corn yields in Kansas

For the first case study, data of corn yields for non-irrigated land irrigated land in Kansas was obtained from the NASS Quickstat database. The data consists of the average yearly corn yield for 9 agricultural districts (see 4.8 for elaboration on agricultural districts) in the period 1980 until 2017, which implies that there 342 observations of the dependent variable, due to the fact that 10 data points are missing however, the number of observations is 332. In table 2, the most important statistical characteristics in this analysis are presented.

Table 2. Descriptive statistics on Kansas corn yields for 9 agricultural districts in the period 1980-2017

variable	obs. (n)	mean (bu/acre)	std. dev. (bu/ac.)	min (bu/acre)	max (bu/acre)
Corn yield	332	72.83	30.17	17.2	163.9

4.5 Case study, heat damage on corn in Kansas: weather data as independent variable

Weather data for the period 1980 until 2017 was downloaded from the NCEI database on the same grid as agricultural districts for the state Kansas. This dataset contains monthly average figures for each district. The selected dataset contains figures for all twelve months on precipitation and maximum temperature. Precipitation is expressed as the district average sum in inches. Maximum temperature is expressed as the average daily highest temperature, so as the sum of each days' highest temperature divided by the number of days in the specific month. The dataset contains therefore 24 data points per year, for 9 districts and 38 years per districts, so the total number of (original) data points is equal to $n = 8.208$. Some of these data points are however irrelevant, think for example of the average maximum temperature of January. Therefore the focus will be on the months June, July and August. Next to the original data, two calculated variables are added because these variables might be of interest. Since temperatures above 85F become harmful for corn production (Schlecker and Roberts, 2008) a variable is added which accounts only for the temperature in Fahrenheit above 85F. Therefore this variable, TMAX85, is calculated as the average maximum temperature in a month minus 85. In a month in which the average maximum temperature is 98F, the TMAX85 variable therefore would be equal to 13. Furthermore a binary variable is calculated, which displays if the average maximum temperature in a month exceeded 85F. This binary variable is therefore equal to 1 if the monthly average temperature was higher than 85F, and equal to 0 otherwise. Descriptive statistics of the above mentioned variables for the months June, July and August are shown in table 3.

Table 3. Descriptive statistics on Kansas weather variables

Var. name	Variable	Unit of acc.	month	Obs (n)	Mean	St. Dev.	Min.	Max.
PCP6	precipitation	Inches	June	342	4.01	2.04	.57	15.35
PCP7	precipitation	Inches	July	342	3.58	2.15	.25	16.43
PCP8	precipitation	Inches	August	342	3.38	1.65	.07	8.28
TMAX6	Avg. max. temp.	Fahrenheit	June	342	86.23	3.76	76.7	95.4
TMAX7	Avg. max. temp	Fahrenheit	July	342	91.66	3.61	83.2	102.5
TMAX8	Avg. max. temp	Fahrenheit	August	342	89.58	3.90	80.6	99.1
TMAX85-6	Max temp ab. 85F	Fahrenheit	June	342	2.26	2.55	0	10.4
TMAX85-7	Max temp ab. 85F	Fahrenheit	July	342	6.67	3.59	0	17.5
TMAX85-8	Max temp ab. 85F	Fahrenheit	August	342	4.76	3.61	0	14.1
TMAXBIN-6	Max temp ab. 85F	Binary	June	342	0.62	0.49	0	1
TMAXBIN-7	Max temp ab. 85F	Binary	July	342	0.98	0.13	0	1
TMAXBIN-8	Max temp ab. 85F	Binary	August	342	0.89	0.31	0	1

4.6 Case study, heat damage on corn in Kansas: relation between temperature and yield

To get a feeling with the relation between yield and temperature before estimating the formal regression model, some statistical facts will be presented and visualized. First, the relation between yield and temperature is plotted in a scatter plot graph. In the presented graph in figure 3, the variables TMAX85-6, -7 and -8 per agricultural district per year are plotted against the yearly average yield for these districts.

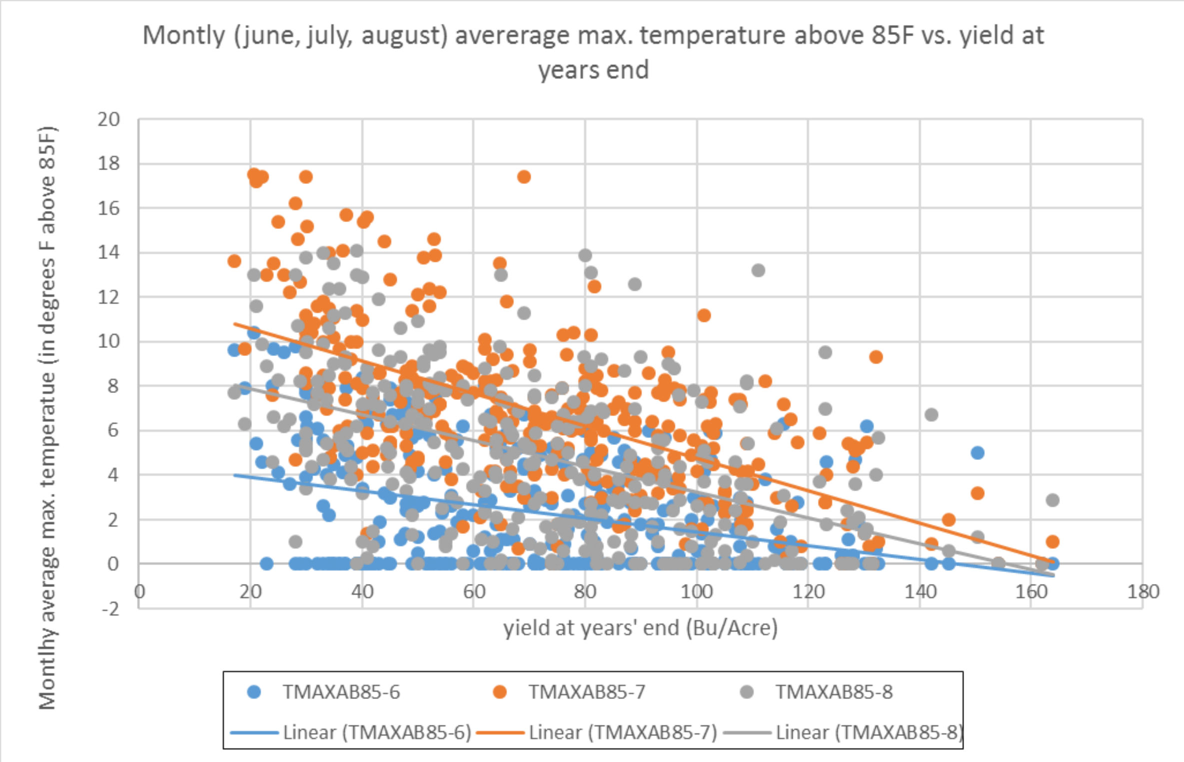

Figure 3. Yield of a district at year's end plotted against TMAX85-6, -7 and -8.

As can be derived from the figure, there is a clear negative correlation between high temperatures and yield. This correlation is found to be the strongest in July ($R^2 = 0.35$). This correlation seems to be rather low, which however makes sense since it is the correlation between yield at year's end and the average maximum temperature in one month. Many other factors impact the yield at years end, such as for example temperature's in other months, soil conditions, wind et cetera.

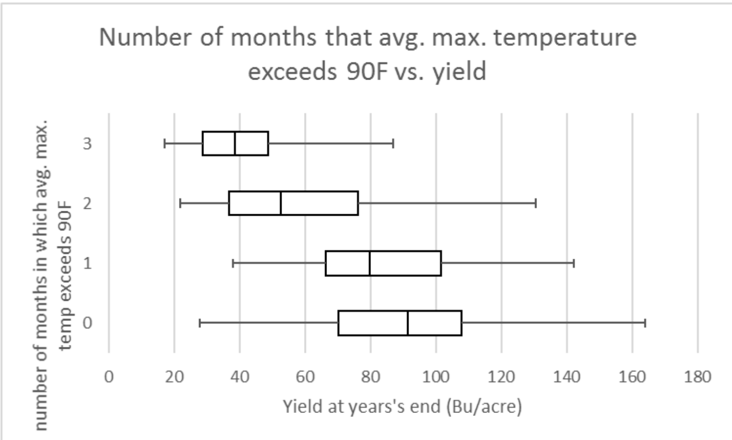

Figure 4. 4-quartile boxplot of Number of months in which the max. avg. temperature exceeded 90F versus the yield at years' end. For 0, 1, 2 and 3 months, respectively n = 79, n = 112, n = 106 and n = 35.

To elaborate further on the relation between yield and high temperatures, a boxplot is plotted and shown in figure 4. This boxplot shows the number of months in which the average monthly maximum temperature exceeded 90F and the distribution of yield across these months. It is visible that in years in which there were relatively much months with average maximum temperatures above 90F, the yields tends to be much lower. This is especially visible in when looking at the middle two quartiles. Furthermore also the maximum yield (right side of the boxplot) in years with many hot months is found to be much lower than in relative cool years. The minimum yield (left side of the boxplot) seems to deviate less. This can be explained by the fact that crop failures can also be caused by other factures than hot weather, think for example of strong winds, flooding, plagues or crop diseases, and therefore can also occur in relative cool years.

4.7 Case study, heat damage on corn in Kansas: long term yield growth in the US

A factor which is likely to impact, and probably even bias, the proposed estimation is the fact that corn yields in the U.S. are gradually increasing over time. Possible causes of this increase might be factors such as advancing agricultural knowledge and technique, and/or ongoing plant breeding. To control for these factors, the linear between time and U.S. nationwide increase in yields is added as a control variable. This variable is equal to 1 for $year = 1980$ and increases to 1.6978 for $year = 2017$.

4.8 Study on the effect of increasing in volatility: area of interest

Comparing agricultural rents of different areas on basis of their agricultural yields can be problematic; agricultural rents are highly dependent on productivity of a plot. This productivity (and thus the yield) is however hard to grasp when the grid of data becomes larger. In, for example, a state different types of agricultural products are grown. This is due to different characteristics of plots across the state such as fertility, type of soil, weather circumstances, altitude et cetera. Assuming that each farmer (lessee) grows the crop which is most suitable for the plot he uses, productivity or yield of a state must possibly be a combination of yields of different agricultural products. To create such a combination of yields, thus one general proxy for agricultural yields is possible. However, also very time consuming and beyond the time available for this thesis. Therefore another strategy is chosen. One area in the United States is selected which highly comparable on basis of agricultural products which are grown; the “Corn Belt” Area. This area is characterized by corn being the major crop for this area, and especially in the heartland of this area forming a monoculture. The Corn Belt Area is highlighted in figure 5, and consists out of the dark green area in the middle of the US

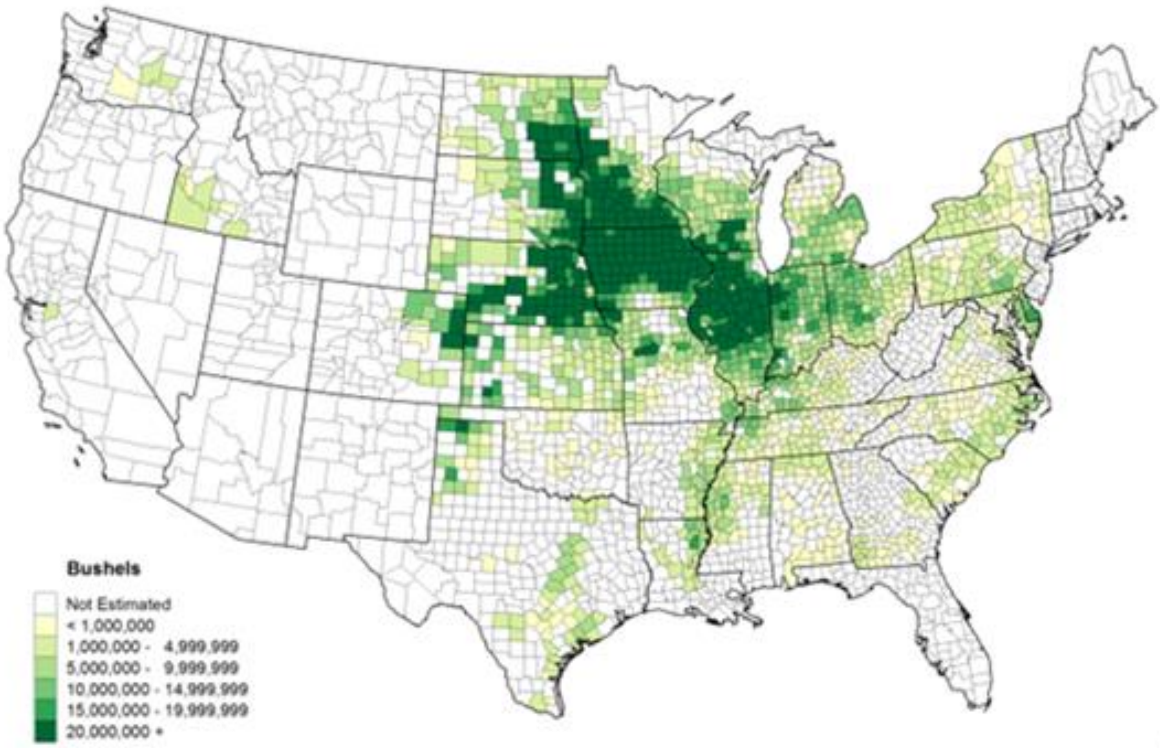

Figure 5: Corn production (in bushel) per U.S. County in 2017. Source: United States Department of Agriculture (USDA).

87 agricultural districts within the Corn Belt region are selected, divided over 15 states. Agricultural districts are spatial subdivisions used by the USDA. Each US state is divided into agricultural districts, for states of average size, the division is normally in 9 to 12 agricultural districts. Therefore each agricultural district consists out of a group of counties. Not all agricultural districts in the Corn Belt are taken into account in this thesis, due to a lack of data on the dependent and/or important independent variable.

4.9 Study on the effect of increasing in volatility: Rent of agricultural land

The dependent variable in second analysis in this thesis is the rental price of agricultural land. This rent represents the average cost in dollar in a specified agricultural district to lease one acre of agricultural land with a one-year lease contract. An acre is a common unit of measurement in American agriculture, and is equal to 4,046.82 square meter. The observations for rent are yearly averages in a certain agricultural district in 2017. Data for 2018 is not complete when this thesis was written.

For all 87 selected agricultural districts the rent for non-irrigated land is obtained. Next to that the rent of irrigated land for 18 of the 87 districts is obtained. For the other 69 districts there is not enough data available for rent and/or yield, mostly because these districts don't have a large share of irrigated land in their total land use. The rents for irrigated land are added as separate rows in the database, adding up to 105 different observations of the dependent variables. Key summery statistics for the dependent variable are shown below in table 3.1. Key summery statistics of four different groups of observations of the dependent variable are given; the total of all dependent variable observations, all observations for rent of non-irrigated land, all observations for rent of irrigated land, and rent for non-irrigated land if there is also a rent of irrigated land in that specific district. It is clearly visible that the rent for non-irrigated land is lower in general, and has a bigger standard deviation. The rent for non-irrigated land in districts where the rent for irrigated land is available, is on average far below the total average rent of non-irrigated land. This is assumable the case since the districts which have a irrigated rent available are located in a dryer part of the United States.

The states for which rent of irrigated land are available are relatively dry states such as Colorado, Kansas, Nebraska and Texas. In table 3.1 it is clearly visible that for these states the difference between irrigated and non-irrigated land is rather big. In some agricultural districts this gap tends to be even much larger; in Northeast Colorado the rent for irrigated land is 328% higher than for non-irrigated land ($32 vs. $137 per acre).

Table 4: Descriptive statistics on dependent variable rent.

Variable	Obs. (n)	Mean ($/acre)	Std. Dev. ($/acre)	Min. ($/acre)	Max ($/acre)
Rent, total	105	145.64	66.04	24	272
Rent, non-irr.	87	139.96	66.51	24	254
Rent, irrigated	18	173.11	57.84	93	272
Rent, non-irr. if rent-irr is avail.	18	76.42	59.77	24	228

4.10 Study on the effect of increasing in volatility: corn yield and yield volatility

To use agricultural production as a proxy for land productivity, the corn production figures of all 105 subsequent states were extracted from the NASS quick stats database. From this data a 15-year average yield was calculated, regarded as the long term average production capacity of a certain agricultural district. The original dataset, with a yearly average yield for each district for 15 consequent years, contained 1,575 data points. The average yields are expressed in Bushel (Bu) per acre. Descriptive statistics on yield are shown in table 5.

Table 5: Descriptive statistics on long-term average production capacity (yield).

(sub)set	variable	obs. (n)	mean (bu/acre)	std. dev. (bu/ac.)	min (bu/acre)	max (bu/acre)
whole set	yield, 15y avg.	105	143.27	37.94	49.53	201.57
non-irrigated	yield, 15y avg.	88	134.85	35.88	49.53	182.73
irrigated	yield, 15y avg.	17	183.98	13.42	151.93	201.57

From table 5 it can be obtained that the average yield for irrigated land is, as might be expected, higher than for non-irrigated land. Also the standard deviation for irrigated land is lower. The production capacity of most productive irrigated land is however still about 33% higher than for the least productive irrigated land. Irrigated land in Southern districts tends generally to have a lower production capacity than in more northern districts. This indicates that even when water supplies are abundant, other factors impact the average yield of district. This might be an indicator that hot weather impacts productivity, even when there is enough water. This can however not be said with certainty, since (also) other factors might play a role, think for example of a difference in soil fertility. The conclusions of the case study on heat damage in Kansas can provide an answer on his topic.

Furthermore, also the volatility of yield in each agricultural district was calculated. This volatility represents the fluctuations of agricultural yields in a certain districts. Descriptive statistics are displayed in table 6. It is obvious and clearly visible that the yield volatility for irrigated land is significantly lower than for unirrigated land. Furthermore yield volatility, in accordance with the dataset, typically tends to be higher in districts where the average yield is relatively low.

Table 6: Descriptive statistics on long-term yield volatility.

(sub)set	variable	obs. (n)	mean (%)	std. dev. (%.)	min (%)	max (%)
whole set	volatility	105	18.17	10.71	4.68	55.11
non-irrigated	volatility	88	20.25	10.52	7.65	55.11
irrigated	volatility	17	8.33	3.64	4.68	18.35

Compared to the results of Tichgelaar et al (2018) presented under section 2.1, the volatility found in the dataset used in this dataset seems rather high; Tichgelaar et al (2018) do find a current volatility of 4.89% in corn yields. The figures of Tichgelaar et al (2018) on yield volatility do however actually have a different definition, and are therefore incomparable. The reported volatility by Tichgelaar et al (2018) is defined as the volatility in the average US yield. 'Bad years' for crop production are often found to be regional, not nationwide (Tichgelaar et al, 2018) and therefore a low production in one area, is often dampened by a good year in another part of the US. The above presented volatility is defined as the average yield volatility in a certain agricultural districts. Due to the smaller grid, the impact of a regional 'bad year' is normally districtwide.

4.11 Study on the effect of increasing in volatility: Long term price discrepancy in corn prices

Agricultural rent and land value are highly dependent on the economic production capacity of land. This economic production capacity is a function of the production capacity in units of weight times the price received for one unit of agricultural product. If a regression of corn yield on land rent would be made without looking to potential spatial differences in corn prices, this would indirectly imply that it is assumed that corn prices are equal across the United States, which is not true. The 'price received' for corn, which is the price which received by farmers for one bushel of corn at a corn elevator (gather point), was downloaded for the 15 selected states for the period 1990 until 2017. Unfortunately there is no data available on the level of agricultural districts on corn price, possibly because some districts do not have their own elevators. In table 7, descriptive statistics per individual state on corn prices are shown. Since prices are obtained for a long (27-year) period, it is assumed that the difference in average price received represents the structural spatial discrepancy in corn prices. This discrepancy is up to 19.7% (Texas vs. North Dakota) for individual states.

Table 7: descriptive statistics on average corn prices received by farmers. Data per individual state for the time period 1990-2017.

State	Obs. (n)	Mean ($/Bu)	Std. Dev. ($/BU)	Min. ($/Bu)	Max. ($/Bu)
Colorado	28	3.22	1.25	1.84	6.86
Illinois	28	3.18	1.29	1.91	6.87
Indiana	28	3.24	1.37	1.88	7.23
Iowa	28	3.10	1.35	1.72	6.92
Kansas	28	3.17	1.30	1.81	7.04
Kentucky	28	3.32	1.28	2.07	6.96
Michigan	28	3.11	1.32	1.78	6.69
Minnesota	28	2.99	1.31	1.60	6.67
Missouri	28	3.20	1.38	1.78	7.34
Nebraska	28	3.11	1.30	1.75	6.85
North Dakota	28	2.89	1.25	1.59	6.46
Ohio	28	3.23	1.37	1.89	7.09
South Dakota	28	2.91	1.33	1.54	6.72
Texas	28	3.46	1.32	2.07	7.12
Wisconsin	28	3.08	1.28	1.77	6.69
Northern states combined	28	3.01	1.30	1.67	6.68
Other states combined	28	3.23	1.32	1.91	7.05

It is likely that the difference in average price received for corn represents some sort of transportation costs. Corn is mostly used as an animal feed and for the production of bio-ethanol (USDA, 2018). The mid-Southern states of the US are the prime location the US cattle industry, the eastern states the heartland of the US pig and poultry industry (USDA, 2018). Therefore it may be expected that these areas face a higher demand for corn. This would explain much of the spatial differences in corn prices, since these areas have a higher average corn price, as can be seen in table 7. We have also seen however that the average yield in Southern states is normally lower than in other states, so it also might be an issue of supply which causes higher prices in these states. Determination of the cause of this issue is however beyond the scope of this thesis.

To test if there is a statistically significant structural difference in corn prices, a two sided t-test is performed. The states of interest are divided in two groups; on one hand the “northern states”, which consist of Michigan, Minnesota, Nebraska, North Dakota, South Dakota and Wisconsin. On the other hand the Southern and Eastern states of the Corn Belt area. Table 8 shows the output results of this T-test. The null hypothesis states that there is no significant difference between the mean corn price received of both groups, the alternative hypothesis states that the mean of both groups do significantly differ. The null hypothesis is rejected at the 99% level. We can assume that corn prices structurally different across states. Therefore the difference between the average long term corn price of individual states from the long term average for all 15 selected states is added in the regression model as a proxy for transportation costs.

Table 8: output results on paired T-test for difference in long-term price received for corn in Northern states vs. Southern and Eastern states.

Variable	Obs. (n)	Mean ($/Bu)	Std. Err. ($/Bu)	Std. Dev. ($/Bu)	95% Conf. Interval ($/Bu)	
Northern	28	3.014	0.245	1.297	2.511	3.516
Other	28	3.235	0.249	1.318	2.723	3.746
Difference	28	-0.221	0.179	0.096	-0.258	-0.184

Mean (difference) = mean (northern – other) t = -12.354
H0: mean (difference) = 0 degrees of freedom = 27
Ha: mean (difference) < 0 Ha: mean (diff) ! = 0 Ha: mean (diff) > 0
Pr (T < t) = 0.0000 Pr (| T | > | t |) = 0.0000 Pr (T > t) = 1.0000

4.12 Study on the effect of increasing in volatility: rent versus yield

The main relation sought after in the second analysis in this thesis, is the relation between rent and agricultural yield volatility. To find out if there is any relation between these two variables, first the relation between rent and yield needs to be addressed. Such a relation might seem obvious; a higher yield implies a higher economic production (since production is a factor of yield and the price received for the commodity produced). Also non-production related issues can play a role, think of for example differences in agricultural policies or taxes in different states. To get a first notion of how rent and yield are related in the data used, they are plotted to visualize their relationship. First, the 15 year average yield is plotted against rent for the whole dataset, which is visualized in figure 6. It is clearly visible that there is a relation between the average agricultural rent in an agricultural district and the average 15 year yield. The R-Squared for the whole dataset is R² = 0,6971. A group of outliers is formed by the points in the upper part of the graph. These outliers are mainly formed by the irrigated districts. Therefore two separate graphs (figure 7 and 8) where plotted to show the relation between rent and average yield of both irrigated and non-irrigated land.

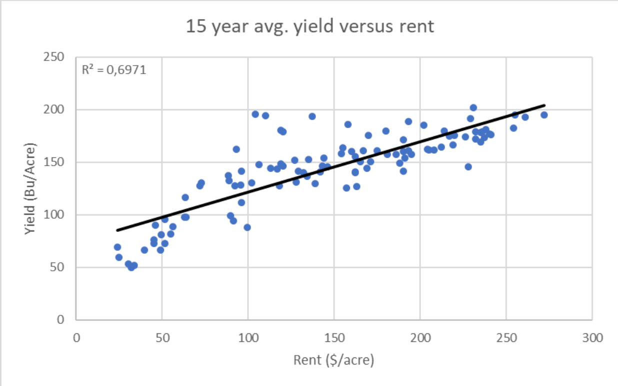

Figure 6: 15 year average yield versus average rent (level:2017) in all 87 agricultural districts, both irrigated and non-irrigated (n=105)

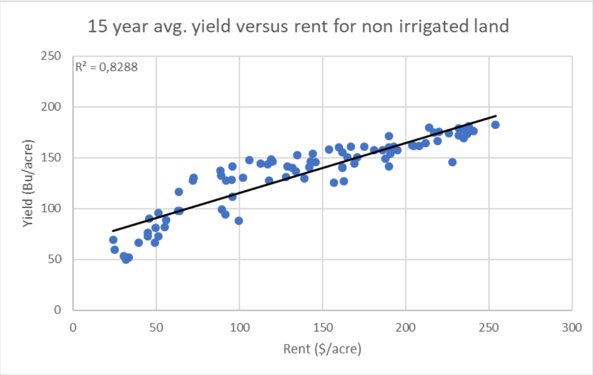

Figure 7: 15 year average yield versus average rent (level: 2017) for all 87 agricultural districts, only non-irrigated.

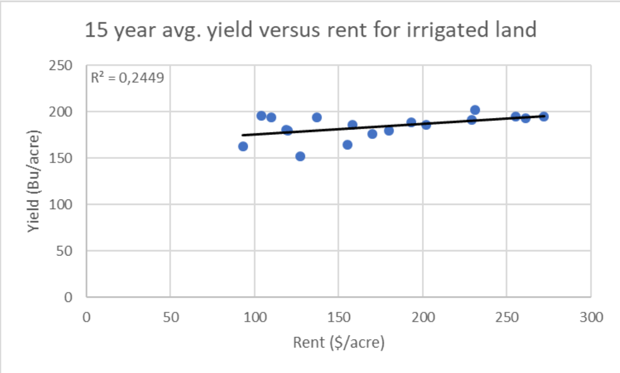

Figure 8: 15 year average yield versus average rent (level: 2017) for 18 districts with data on irrigated rent and yield available

For non-irrigated land, this relation is relatively strong, with $R^2 = 0.8288$. For irrigated land the relation seems to be much less strong with an $R^2 = 0.2449$, although the relative small availability of data (n=18) is a weakness in this analysis. If it is assumed that the relation between rent and yield is causal, there must be some sort of discrepancy in the net economic production capacity of a plot. Firstly a difference in the price received for corn might play a role, as discussed under 3.8. Next to that, a difference in production costs related to irrigation might play a role, for example because of a difference in the depth that must be reached to be able to extract ground water and the aligned difference in energy consumption that is needed to extract water. See also 2.6.

4.13 Study on the effect of increasing in volatility: Yield corrected rent versus volatility

To find out if any relation between rent and volatility is prevalent, a new variable is created; yield corrected for rent. This variable is created by dividing the average yield in a certain agricultural district by the average rent in a certain district. Therefore the variable shows how much yield can be obtained in a certain agricultural district by paying one dollar of rent. Next, this yield corrected rent of a specified agricultural district is plotted against the volatility of a certain agricultural district. The resulting graph is shown in figure 9. When corrected for rent, a relation between volatility and average yield per dollar rent seems to be prevalent. In chapter 5 the causality of this relation will be tested to find out if yield volatility impacts the average rent of a certain agricultural district significantly. If such a relation proves to be significant, the estimations of Tichgelaar et al (2018) with regard to the increase of yield volatility by an increase of temperature, can be used to estimate the impact of increasing yield volatility on rents. Combined with the findings in the first case study on impact on agricultural yields, this allows us to estimate the impact of a change in temperature on agricultural rents and eventually land values.

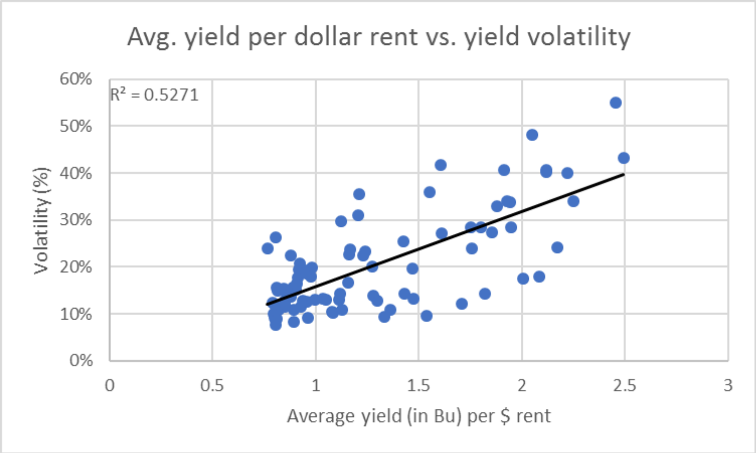

Figure 9: Yield corrected for rent versus volatility of agricultural districts.

5. RESULTS

5.1 Case study heat damage on corn in Kansas: the effect of high temperatures on yield.

To answer the first research question, the relation which is indicated under chapter 4.6 needs to be tested for its significance and significance. As stated under 3.1 this will be done by exploiting a panel data regression model. In this regression model, the variables TMAX85-6, TMAX85-7 and TMAX-85-8 are used as main independent variables. As control variables for rainfall PCP6, PCP7 and PCP8 are added (see 4.5). Also the long term yield growth for corn in the United States will be added, to control for advancing agricultural technology.

Firstly it needs to be checked if there is correlation prevalent in the model between the errors and regressors. If there is any correlation prevalent a fixed effects model needs to be used, otherwise it is statistically allowed to use the preferred random effects model. This check is done via a 'Hausman-test'. By running the Hausman-test it is obtained that the random effect model cannot be used in the main regression model and that a fixed effects model thus is appropriate (Wooldridge, 2015). Results are shown in table 9. As can be seen in the output, high average maximum temperatures in June, July and August all prove to impact agricultural yield significantly at the 1% level. The impact of high average maximum temperatures tends to be the most severe in July. Precipitation in general doesn't seem to have a significant impact on yield, only precipitation in July proves to have significant impact at the 10% level. Control variable usyieldgrowth, which controls for long term yield growth due to advancing agricultural techniques and plant breeding proves to be, as expected, also highly significant. Note that this variable grows at a constant rate each year from 1 in 1980 until 1.7 in 2017.

Table 9: output results of main regression model for case study of the effect of high temperatures on corn yields in Kansas.

	(1) Main model
TMAX85-6	-1.5012*** (0.5198)
TMAX85-7	-2.4970*** (0.4421)
TMAX85-8	-1.4815*** (0.4040)
PCP6	0.2674 (0.6983)
PCP7	1.2666* (0.5853)
PCP8	0.2293 (0.7669)
USYIELDGROWTH	54.0934*** (4.9003)
Constant	21.0795** (0.021)
Observations	332
R-squared	0.553

*Note: The model includes constant term and fixed effects per agricultural district. Standard errors in parentheses with *** , **, * indicating significant at 1%, 5% and 10%, respectively.*

The parameters that this regression delivers can be used in an estimation which predicts the effect of an increase in temperature on corn yields in Kansas, which allows also to make a prediction on a possible change in land values that is aligned with this change in corn yields. This can be done both directly with use of this estimation or by implementing findings in the estimation that is made under 5.2. See conclusions and discussion for further elaboration.

5.2 Case study heat damage on corn in Kansas: model performance

The performance of under 5.1 presented model is back tested on the original dataset, by using the datapoints as input and comparing with the actual yield figures in the dataset. This leads to the following performance indicators.

Table 11: model performance indicators

indicator	performance
Average yield (n=332)	Original dataset: 72.83467 Estimated results: 72.83494 0.00036% structural overestimation
average absolute difference between estimations and original yield data (n=332)	16.24947 bu/acre (22.31% average absolute difference)
Median absolute difference between estimation and original yield data (n=332)	14.413 bu/acre (19.79% median absolute difference)
Number of estimations where difference between actual and estimated bu/acre exceeds 25bu (about 1/3th of average yield)	72 estimation (22% of estimations with n=332 in total)

As can be seen in the table, there is an average overestimation of 0.00036% in the estimation output results compared to original results. Furthermore there is a 19.79% median deviation between model estimation results and actual yield figures. This median deviation seems rather large. This however can (partly) explained by the fact that $R^2 = 0.55$, which implies that about 45% of the variation of yield is not explained by the model. This variation is due to other factor then high temperature and precipitation. Think for example of differences in soil quality, the occurrence of strong winds, plagues et cetera.

5.3 Case study heat damage on corn in Kansas: estimation of the effect temperature increase

The presented estimation result now can be used to estimate the effect of an increase in temperature on Kansas corn yields. As stated in Table 3, average maximum temperatures in Kansas over the period 1980 until 2017 for June, July and August are respectively 86.23F, 91.66F and 89.58F. in table 11 the estimation results are used to calculate the effect of respectively a 1C, 2C, 3C and 4C increase in temperature.

Table 11: Impact estimation of an increase of temperature by 1, 2, 3 and 4 degrees Celsius accompanied by confidence intervals.

Temperature increase in C	estimated avg. yield in bu/acre	% loss compared to present	One std. rev. range (68% confidence)	Two std. rev. range (95% confidence)	Estimation Tichelaar et al.
Present (0C)	72.83	Not applicable	Not applicable	Not applicable	Not applicable
1C	62.47	14.23%	-3.40% until -25.06%	+7.43% until -35.89%	Not stated
2C	52.81	27.77%	-13.56% until -41.98%	+0.64% until -56.18%	15.11%
3C	42.74	41.31%	-23.73% until -58.89%	-6.15% until -76.48%	Not stated
4C	32.63	55.20%	-34.18% until -76.22%	-13.16% until -97.23%	42.54%

The table shows the effect of increase of temperature on Kansas corn yields. From little above a 2 degrees increase in temperature it can be said with 95% confidence that corn yields in Kansas are expected to decrease. An increase of temperature with 4C would cause an estimated decrease of more than half of the current production. In the most right column, the results of Tichgelaar et al (2018), discussed under 2.1, are added for comparative use. It needs to be kept in mind the results of Tichalaar et al (2018) show the total expected decrease in US corn yield. Some areas in the U.S. might however face much less decline of corn production due to global warming, such as for instance area's in the north and east of the country. It is not even unthinkable that some of the most northern areas would actually face an increase in yields when temperatures rise modestly. Kansas is however located at the southern border, and thus a hotter and dryer part of the US corn producing regions, and therefore may be expected to be hit harder by an increase in temperature. This is also supported by the presented results. Further conclusions and implications of this table are discussed under chapter 6 and 7.

5.4 Study on the effect of increasing in volatility: the effect of increasing yield volatility on rent

To study the effect of a decrease in yields and an increase in yield volatility a hedonic pricing model is used. As stated under 3.2, this hedonic pricing model will regress long-term average yield and yield volatility per agricultural district, amongst some control variables, on rent levels. This is done in several specified models. In the first model, which is the main regression model, yield and yield volatility will be regressed separately on rents. Next to that there are control variables on population density (to control for the effects of urbanization), irrigation status (to control for if a row variables belong to irrigated land or not) and a dummy variable. The dummy variable is used to control for categorical effects. The dummy variable 'top5state' refers to whether the agricultural district is located within a top 5 corn producing state or not.

Next to the main regression, the same regression model will be executed for only the data on unirrigated land, to see if for this subgroups significant differences are found with regard to irrigated land. Furthermore two regression models (again for both all data and for unirrigated data only) will be executed in which a combined variable is used which combines yield and yield volatility into one index. This is done due to the fact there tends to be a high correlation between yield and yield volatility. Districts with a relative low average yield often tend to have a high volatility and this effect is also present the other way around. In the table below an oversight of the correlation between the used variables in the regression model is presented.

Table 12: correlation between used variables in second regression (hedonic pricing model).

	Rent	15y-av-yield	Yield vol.	Irr. Status	Struc.p.diff	popdens	Top5state
Rent	1.0000						
15y-av-yield	0.8349	1.0000					
Yield vol	-0.7157	-0.8970	1.0000				
Irr. status	0.1901	0.4904	-0.4303	1.0000			
Struc. p. diff.	0.0077	0.0798	0.0875	0.1795	1.0000		
popdens	0.1484	0.1681	-0.1741	-0.1612	0.1509	1.0000	
Top5state	0.5767	0.3123	-0.2194	-0.1045	-0.0077	0.0237	1.0000

Correlation between independent variables, or multicollinearity, affects the reliability of individual coefficient estimates. It however does not affect the reliability of the model as a predictive instrument when estimating changes in the dependent variables when changing the value of the independent variables (Wooldridge, 2015). Since the purpose of this thesis is mainly to estimate the impact of changes in yield and yield volatility on rents, a model with collinearity in its independent variables is still usable tool to estimate the overall impact of a change in rent when temperatures increase. The contribution of individual parameters to this change in rent however becomes less certain when multicollinearity is prevalent.

To grasp also the (reliable) impact of the control variables on rent, an analysis in which an index for the combination of yield and yield volatility is used. This index was calculated for each data point by firstly subtracting the lowest value in the column from the individual data point, and next dividing the outcome by the highest value, this leads to an index of both 0 to 1 for yield and yield volatility. Next, for yield volatility this value was 'turned around' by subtracting the value from 1. In this way both the index for yield an yield volatility are 0 for the 'worst' value and 1 for the 'best' value, assuming that a farmer want to keep his volatility as low as possible. To come to the combined index, these individual values are simply added. Therefore, in theory, the 'worst' district to grow corn (low yield, high volatility) has a value of close to 0 and the 'best' district has a value close to 2. Furthermore a fourth regression analysis will be added, which omits the yield volatility variables, to see how this relates to the specification in which this variable is included. Therefore there are in total 3 regression specification used, the original specification, the specification with use of only unirrigated data and the specification with unirrigated data *and* use of index for the combination of yield and yield volatility. The results are shown in table 13 (next page).

Table 13: Estimation results of the regression of agricultural yield, yield volatility and control variables on agricultural rent, with four model specifications.

	Specification 1 **(all data, no index)**	Specification 2 **(unirrigated data, no index)**	Specification 3 **(unirrigated data, use of index)**	Specification 4 **(unirrigated data, volatility omitted)**
15-year avg. yield	1.6634 (0.1880)***	1.7979 (0.1666)***	-	*1.5304* *(0.0844)****
15-year avg. volatility	73.7321 (62.5376)	100.6411 (54.2968)*	-	-
Index yield and volatility comb.	-	-	107.3368 (7.4321)***	-
Structural price difference	-0.6566 (0.7853)	0.4991 (0.7070)	1.8055 (0.8145)*	0.9354 (0.6765)
Irrigation status	-33.8933 (9.283433)***	-	-	-
Population density	-0.0090 (0.0170)	-0.0413 (0.03775)	-0.01722 (0.0180)	-0.01853 (0.0147)
Top-5 state	37.5989 (6.1234)***	27.7825 (5.8052)***	38.3937 (6.6946)***	29.8355 (5.7826)***
Constant	-116.4723 (36.4882)***	-133.7533 (31.9306)***	-22.3584 (9.3553)**	-77.6246 (10.2770)***
Observations	105	87	87	87
R-squared	0.8357	0.8837	0.8286	0.8729
F-statistic	88.23	123.13	99.08	148.64

*Note: The model includes constant term and fixed effects per agricultural district. Standard errors in parentheses with *** , **, * indicating significant at 1%, 5% and 10%, respectively.*

As can be seen from the table, agricultural yields seems to have a highly significant impact in both the 1st and the 2nd specification. It however needs to be kept in mind that there are is collinearity in the independent variables, which can impact the reliability of these estimators. Furthermore yield volatility is found to have only some significant impact for the specification which only takes the unirrigated data into account. Structural price difference in corn prices don't seem to have a highly significant impact on rents. Population density is not found to have any significant effect on rents in any of the specification too. Dummy variable Top-5 state is however found to be highly significant. A possible explanation of this effect might be that the top-5 corn producing states are possibly also those states which have the most suitable growing conditions for corn, not only climate conditions but also for example most suitable soil types. It needs to be kept in mind again that specification 1 and 2 have a relative large collinearity issue. To estimate the impact of individual control variables and interpretation of their individual estimations coefficients, specification 3 is most suitable, since the used index in specification 3 counters the most severe collinearity. As stated before however, the main goal of this thesis is to estimate the total impact of change climate rather than investigating the individual parameters.

For specification 1 and 2, the sign of coefficient parameter of yield volatility is positive. This is counterintuitive, since an increase in volatility and thus risk, under normal asset pricing is typically expected to have a negative impact. There is a high chance that his effect might be due to the collinearity be caused by bias in the estimation. Furthermore yield volatility is not found to have a highly significant impact on rents. This is supported by the fact that specification 4, which completely omits yield volatility as a variable has an R-squared, and thus explanatory power, which is just 0.0108 below the R-squared of specification 2.

For all model specifications, the variance inflation factor (VIF) for each of the individual independent variables is calculated to find out how severe the collinearity between the independent variables is. The results are shown in table 14. In literature there is no ‘hard’ rule which value for the VIF is acceptable or which value is considered to be too high. Some scientists believe that 10 is the maximum acceptable level for VIF, while others see 5 as the maximum level for VIF (Hair et al, 2013). With VIF>5 in specification 1 and 2, at least it can be said that the interpretation of coefficients and their properties in specification 1 and 2 can be problematic. By taking into account these problematic VIF values, the counterintuitive sign of yield volatility in specification 1 and 2 and the fact that yield volatility does not contribute greatly to a high R-squared, it makes sense to regard the fourth specification as the most suitable and reliable for estimation purposes.

Table 14: Values of Variance Inflation Factor for each individual independent variable in each used specification.

	Specification 1		Specification 2		Specification 3		Specification 4	
	VIF	**1/VIF**	**VIF**	**1/VIF**	**VIF**	**1/VIF**	**VIF**	**1/VIF**
15-year avg. yield	6.98	0.14	5.63	0.18	-	-	1.40	0.71
15-year avg. volatility	6.14	0.16	5.13	0.19	-	-	-	-
Index yield and volatility comb.	-	-	-	-	1.35	0.74	-	-
Structural price difference	1.26	0.80	1.19	0.84	1.09	0.92	1.06	0.94
Irrigation status	1.62	0.62	-	-	-	-	-	-
Population density	1.20	0.83	1.18	0.84	1.18	0.85	1.17	0.86
Top-5 state	1.27	0.79	1.34	0.75	1.22	0.82	1.29	0.78
Average	3.06	0.33	2.89	0.35	1.21	0.83	1.23	0.82

I5.5 Study on the effect of increasing in volatility: model performance

As done for the previous model, also this model (specification 4) will be tested on the original data to measure its predictive power and performance. The most important indicators are shown in table 15. A 0.26% structural overestimation of rent is found. Next to that there is a 13.04% average absolute difference between estimation results and the actual data on rent. The median absolute difference is 9.49%. There are 5 of the 87 estimations which differ more than 50% from the actual rent figure. In every case this concerns agricultural districts in which the rent is below average. It is however unclear what exactly causes these large difference between these estimations and the actual rent.

Table 15: second model (specification 4 of table 13) performance indicators

indicator	**performance**
Average rent (n=87)	Original dataset: 139.9598 Estimated results: 140.3242 0.26% structural overestimation
average absolute difference between estimations and original rent data (n=332)	$18.24 (13.04% average absolute difference)
Median absolute difference between estimation and original yield data (n=332)	$13.29 (9.49% median absolute difference)

5.6 Study on the effect of increasing in volatility: effects of temperature increase on rent

The chosen specification (specification 4) can be used to estimate the impact of changing agricultural yields on rent. The estimated decrease in US average yield found by Tichgelaar et al (2018). is used to estimate the impact (a -15% and -43% decrease with a temperature increase of respectively 2C and 4C) of temperature increase on rent. In figure 10, the estimation results of specification 4 are plotted. For this graph it is assumed that the control variables don't change over time, and thus only yield changes. As can be seen in figure 10, a one-percent decrease in yield leads to an above one-percent decrease in rent, 1.48% to be precise. Results and implications are discussed further under chapter 6.

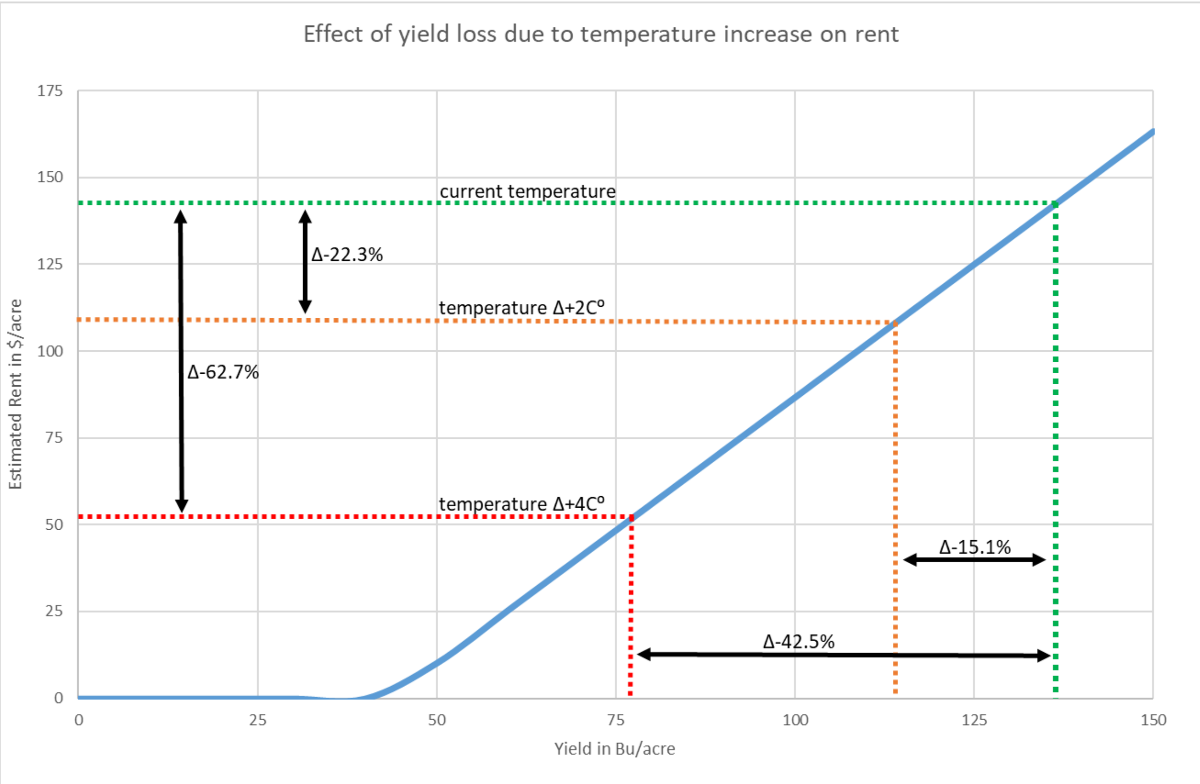

Figure 10: estimation result of the effect of yield on rent plotted, with control variables ceteris paribus. The effects of a 2C and 4C increase of temperature are marked with the orange and red dashed lines.

6. DISCUSSION

6.1 The effect of high temperatures on corn yields

As stated in table 11, an increase in temperature has a significant impact on corn yields. For Kansas, it was found that an increase of temperature by Δ1C leads to a decrease of corn yields by around 10 bushel per acre. An increase of temperature by 2C leads to decrease of corn yields in Kansas of 27.8% and an increase of temperature by 4C leads to decrease in corn yields by as much as 55.2%. These findings are in line with the earlier mentioned results of Tichgelaar et al (2018). Kansas faces a higher estimated decrease in yields compared to the US average as presented by Tichgelaar et al (2018). Some (future) effects which may impact the actual future yield are not captured in this analysis. Some of these might severely impact the actual future yield. For example advancing genetically modification of crops may play a critical role. See discussion under 6.3 for elaboration on this topic.

6.2 The effect of decrease in yields and increase in volatility on rents and land values

Table 13 shows 4 different estimation model specifications with regard to the effect of yield and yield volatility on rent. Yield volatility wasn't found to highly significantly impact rents. Yield volatility was however found to be highly correlated with yields. The addition of yield volatility into a model specification did not raise the predictive power (R-squared) significantly. Therefore the specification without yield volatility was chosen for estimation purposes.

The impact of yield on rent tend to be highly significant and large. A decrease of agricultural yield by 1% leads to an estimated decrease of rents by 1.47%. This can be explained by the fact that agricultural production is inherently connected to production costs, such as the usage of machinery and the need of seedlings. One can expect that these costs remain similar, or at least don't equal marginally decline, when production levels decline. Therefore in this analysis it was found that rent is equal to zero when production falls below 43.3 bushels per acre. One thus may expect that below 43.3 bushel per acre production, production costs are higher than revenue.

In 2017, 84.7 million acres of land was used for corn production (USDA NASS Quickstats, 2019). This implies a rental value of all land used for corn in 2017 was equal to $11,864,700,000. This total rental value can decline with 22.3% and 62.7% by respectively an increase in temperatures of 2C and 4C. The land values of an acre of cropland in the United States was equal to $4.090 in 2017 (USDA, 2017). This implies that the gross initial yield on leased out cropland was 3.5%. The total value of the cropland in use for corn production in 2017 was $346,423,000,000. A 2C and 4C increase in temperature would therefore imply that that total risk at value for US corn land therefore is equal to respectively $78,638,021,000 and $217,207,000,000. This prediction is however heavily dependent on several ceteris paribus assumptions. This is discussed further under 6.4.

6.3 Exogenous factors which might impact the effect temperature increase on production (yield)

Both the presented results and the earlier work of Tichgelaar et al (2018) do only account for the effect of the change in temperature on corn production. Changes in other weather variables due to climate change are however also very likely. Examples can be changes in precipitation (rainfall), wind patterns, sunshine, humidity and possibly other weather variables. These changes can strengthen or soften the effect of temperature increase on agricultural yields. Less precipitation or an increase in (strong) winds might for example negatively impact agricultural yields. It is however hard to predict how these weather variables will change in the future. For many area's in the heartland of US crop producing areas which are expected to face a decrease in rainfall as well, these predictions do however have a high degree of uncertainty (IPCC, 2018). It is therefore hard to make reliable predictions on the effect of changes in these weather variables on yields and eventually land values. Furthermore human factors can play a role in the future of effect of high temperatures on agricultural yields. As stated under section 5.1, US agricultural yield have on average grown with a more or less constant rate, mainly due to advancing agricultural technologies, agricultural knowledge and plant breeding (Schlecker&Roberts, 2006). It is hard to predict if and by how much these human factors continue to lift agricultural production. Next, genetic modification of plants can be disruptive in this analysis. Currently several parties (both non-profit and commercial) are investigating the opportunities to 'create' heat tolerant crops trough genetical modification. If such heat tolerant plants can be developed and are found to be safe for (human) consumption this could partly mitigate the effects of climate change (Roy et Al, 2011).

6.4 Highest and best use of agricultural land

One of the biggest limitations of the presented model is that it does not consider the 'highest and best use' of agricultural land. If temperature rises and thus agricultural yields are (severely) impacted, other uses might be more beneficial. The presented results are based on the assumption that area's which are now mainly dominated by corn production will remain producing corn disregarding changes in the suitability of the area to produce corn. In reality however, it is not unthinkable that farmers shift to other types of agricultural products which have a higher heat tolerance. Also other use then growing crops are thinkable, for example use as pastureland, which is mainly used to let cattle graze (ranches). The areas south of the 'Corn belt' and Kansas, such as Oklahoma and the middle part of Texas are mainly in use as pastureland. With an increase of temperature, climate conditions for Kansas and areas further up north might be in the future somewhat similar to nowadays Texas and Oklahoma. Rents for pastureland are however found to be significantly lower than for cropland. In 2017 they ranged from $10 to $30, while rent for cropland in Kansas was equal to $60 (USDA, 2018). A model which captures the future highest and best use of areas when temperatures increase can be made, it however would also imply a severe increase in data and workload to carry out such a model.

A proposition for a model which captures changes in highest and best use (amongst other things) is be made under 6.6.

6.5 Changes in agricultural commodity prices

Rent and land value of a certain plot are highly impacted by the economic production capacity of that plot. This economic production capacity depends partly on the price of the agricultural good that is produced on the plot, in other words; higher commodity prices lead to higher rents and land values. A future shift in agricultural commodity prices is therefore very likely to cause also a shift in rent and land value. In the presented analysis, time-variation of corn prices do not play a role. This is the case since all data on rent is selected from one specific point in time; the 2017 average. Spatial differences in commodity prices are covered under 4.11.

A future shift in production due to temperature increase (or due to any other factor) is likely to cause a shift in rents and land values. Including agricultural commodity prices in this analysis is however also problematic; it would also require us to make a future prediction for the commodity price input in the model. Forecasting commodity prices is hard, especially when time frames get larger. Unforeseen causes of events can shift commodity prices dramatically, and don't necessary have to do with climate changes. Think for example of policy changes such as tariffs or trade agreements, but also natural factors/events such as pests or plagues.

6.6 Proposal for in-depth research to assess the impact of climate change on land values

The presented model in this thesis functions as an example rather than a total in-depth research model to estimate the total impact of climate change on land values. This thesis however can function as guideline to carry out a larger investigation on this topic. In this paragraph some directions will be given how a more in-depth investigation can be carried out following the below proposed steps. By following these steps, (much of) the shortcomings discussed before can be evaded.

1. For the regression of (maximum) temperatures on agricultural yields, ideally, a small grid must be chosen. For the United States an ideal grid would assumable be on county- or municipality level. This is necessary since the impact of high temperature on crop growth might differ spatially, due to spatial differences in other factors than temperature such as soil type, soil moisture, wind dynamics, slope of land et cetera.
2. To consider highest and best use, temperature variables should be regressed on all important crops which are grown within a certain grid. This means that the yields over time of each agricultural product in each area should be regressed individually on temperature variables.
3. Next, for each agricultural product in each area the effect of a shift in temperature on the yield should be calculated (predicted) with the individual regression parameters.

4. For each type of agricultural product, a regression of average yield on rent should be performed. Ideally this is done on small grids and an individual basis too, to control for spatial differences in production costs. If data of different points in time is used (so with historical rent-yield combinations) also agricultural commodity prices on that specific point in time need to be included, to control for changes in the commodity prices.
5. The results found under 3 can be included in regression 4 to calculate which agricultural product (or other use) implies the highest rent for the individual areas. This would be the highest and best use. Since prices for agricultural goods do capture the demand for these goods to some extend *and* these prices are reflected in the rent (see chapter 2) also demand for types of agricultural goods are taken into account. Future shifts in demand for these goods are however not taken into account, unless also step 7 is included in the analysis.
6. Now the decrease in rent for the individual area's and the total area of interest can be calculated, and therefore also the total risk at value for agriculture due to temperature increase for the total area of interest.
7. Agricultural commodity prices can be included in the regression model proposed under 4, this is however only relevant if also any trustworthy predictions or directions about future shifts in commodity prices are available, which is in practice generally not the case.

By following the proposed guidelines, a more concise estimation of the possible risk at value in agricultural real estate due to climate change can be made. A concise estimation can contribute to the discussion about investments in countering climate change. Furthermore it can help farmers, land owners, banks, (agricultural) insurance companies and policy makers to adapt early to future changes in value of agricultural real estate and the impact of these changes.

7. CONCLUSION

This thesis was meant to assess if, and how, temperature increase due to climate change impacts agricultural real estate. It was found that an increase in temperature is expected to decrease land values due to decreasing production. In a case study which assessed the effects of high temperatures on Kansas corn yields, it was found that corn yields can drop up to an estimated 55% in Kansas if temperatures increase by 4 degrees Celsius. Furthermore it was found that rents are highly impacted by average agricultural yields, and that a 1% decrease in yields causes a more-than-1% estimated decrease in rent. If temperatures increase by 4 degrees Celsius, rents drop by an estimated 63% on average in the United States. To estimate the impact of decreasing yields on rents, an extensive an large investigation has to take place, in which most importantly the model should also consider 'highest and best use'.

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