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Projected Changes in Insurability and Affordability of Insurance Coverages due to Climate Change

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Projected Changes in Insurability and Affordability of Insurance Coverages due to Climate Change

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Glossary

Term	Definition
Federal Crop Insurance Program (FCIP)	Coverage for farmers that is overseen and subsidized by the federal government and marketed and serviced by private insurers and agents. Federal crop insurance offers an array of insurance policies that cover loss of crop value arising from extremely hot weather, drought, excessive moisture, flood, wildlife damage, earthquake, insects, and disease. These policies protect a farmer against production or revenue losses when a particular insured crop does not meet a preset production guarantee. The Risk Management Agency (RMA) of the U.S. Department of Agriculture oversees the federal crop insurance program. RMA provides policies for more than 100 crops, the majority of U.S. crops, although coverage may not be available for some crops in some areas.[1] For a more detailed history, please visit the Insurance Information Institute[7].
Climate Change	An overall alteration of mean climate conditions.
Pest	Any organism or microorganism that harms or kills crops and reduces the value of crops before and after harvest.
Climate	The prevalent pattern of weather observed over a prolonged period of time.
Climate Variability	Fluctuations about the mean.
Base Price	The insurance price projected just before planting time.

[1] https://www.irmi.com/term/insurance-definitions/federal-crop-insurance

Term	Definition
Harvest Price	The Harvest Price Option is revenue or price coverage within the crop insurance policy that provides protection on lost production at the higher of the price projected just before planting time or the price at harvest. Projected price is just an estimate of the final price, per se and farmers pay an additional premium for this type of price protection. It is similar to the concept of paying an indemnity at "replacement value," similar to what is available for homeowners insurance. It enables the producer to acquire the lost production at its replacement cost.
Palmer Drought Severity Index (PDSI)	Attempts to measure the duration and intensity of the long-term drought-inducing circulation patterns. Long-term drought is cumulative, so the intensity of drought during the current month is dependent on the current weather patterns plus the cumulative patterns of previous months. Since weather patterns can change almost literally overnight from a long-term drought pattern to a long-term wet pattern, the PDSI can respond fairly rapidly.
Palmer Hydrological Drought Index (PHDI)	Measures hydrological impacts of drought (e.g., reservoir levels, groundwater levels, etc.) which take longer to develop and longer to recover from. This long-term drought index was developed to quantify these hydrological effects, and it responds more slowly to changing conditions than the PDSI.
Palmer Modified Drought Index (PMDI)	Attempts to measure the duration and intensity of the long-term drought-inducing circulation patterns. Long-term drought is cumulative, so the intensity of drought during the current month is dependent on the current weather patterns plus the cumulative patterns of previous months. Since weather patterns can change almost literally overnight from a long-term drought pattern to a long-term wet pattern, the PDSI can respond fairly rapidly.
Palmer Z Index	Measures short-term drought on a monthly scale.
R-squared (R^2)	A statistical measure that represents the proportion of the variance for a dependent variable that's explained by an independent variable or variables in a regression model. Whereas correlation explains the strength of the relationship between an independent and dependent variable, R-squared explains to what

Term	Definition
	extent the variance of one variable explains the variance of the second variable. So, if the R^2 of a model is 0.60, then approximately sixty percent of the observed variation can be explained by the model's inputs.
P-value	For a given coefficient estimate, the p-value is an estimate of the probability of a value of that magnitude (or higher) arising by pure chance. For example, suppose a certain variable in our model yields a coefficient of 1.5 with a p-value of 0.0012. This indicates that, if this variable's true coefficient is zero, the probability of getting a coefficient of 1.5 or higher purely by chance is 0.0012.3 In this case, it may be reasonable to conclude: since the odds of such a result arising by pure chance is small, it is therefore likely that the result reflects a real underlying effect—that is, the true coefficient is not zero. Such a variable is said to be significant. On the other hand, if the p-value is, say, 0.52, it means that this variable—even if it has no effect—is much more likely to yield a coefficient of 1.5 or higher by chance; as such, we have no evidence from the model output that it has any effect at all. Note that this is not to say that we have evidence that it has no effect—it may be that the effect is actually there, but we would need a larger dataset to "see" it through our model.
Oury Index	An aridity index that combines temperature and precipitation information that can capture more impact on crop production than a single measure of temperature or precipitation.
Temperature-humidity index (THI)	A combined measure of temperature and relative humidity that has been shown to have significant impacts on livestock production.
Blockchain or Distributed Ledger Technology (DLT)	A ledger of individual blocks of data, linked and secured through encryption technology (hashes). Copies of the ledger are stored on a distributed network and updated when a transaction occurs.

Executive Summary

The Society of Actuaries Catastrophe/Climate Strategic Research Program engaged Risk & Regulatory Consulting LLC (“RRC”, “we”, “our”, or “the researchers”) to conduct research on the projected changes in insurability and affordability of insurance coverages due to climate change.

RRC researched the potential impact of climate change on crop insurance availability and affordability. The researchers leveraged multiple studies to analyze the impact of climate change on crops and U.S. agricultural productivity, and the associated implications for crop insurance pricing, including the Federal Crop Insurance Program (“FCIP”), with emphasis on the Midwest region of the United States.

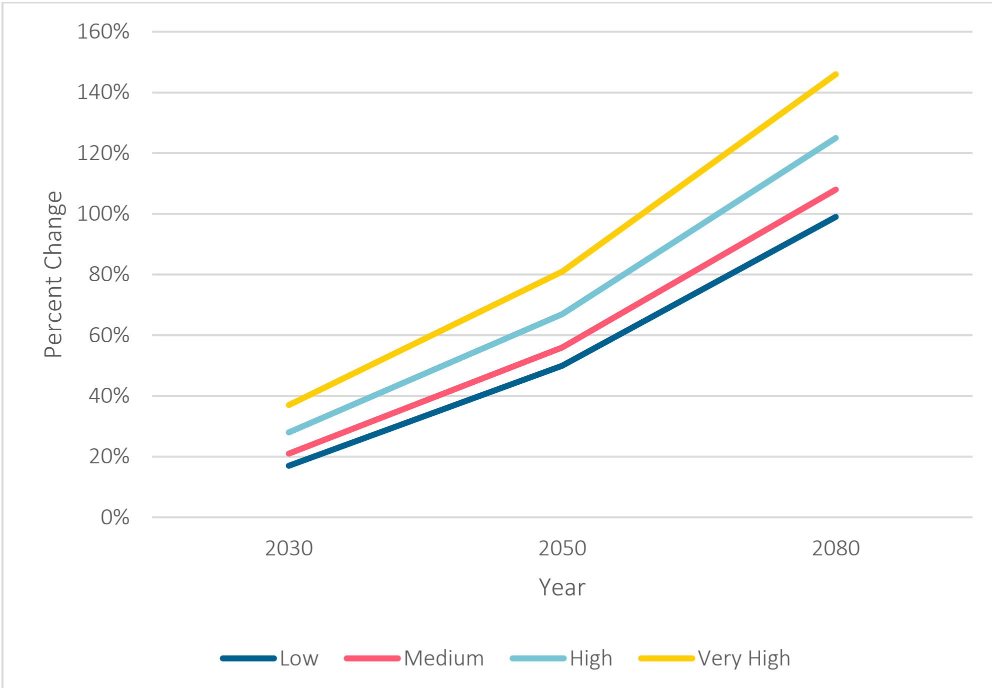
RRC conducted a case study of the Midwest region, which included modeling crop insurance prices and forecasting projections of those prices into the future. RRC also looked into the potential impact of new innovations on crop insurance, including Blockchain, FarmersEdge, and Index Insurance.

Multiple observations were made in the course of the analysis. Absent changes to program design, the research finds that the cost of the FCIP is likely to increase, driven by a combination of increasing overall variability of prices and yields, and higher prices driven by lower supply[2]. Future crop yields are expected to be more strongly influenced by anomalous weather events than by changes in average temperature or annual precipitation[3]. Significant variation in impacts of climate change were observed by crop and between geographic regions, including state to state. Based on our analysis, we believe that crop prices could increase 99% to 146% for Corn, 28% to 51% for Soybean, 110% to 145% for Spring Wheat, and 50% to 68% for Winter Wheat, respectively, by 2080[4]. These price increase could cause serious implications for the future of affordability and availability of crop insurance if the FCIP becomes too cost prohibitive to insureds without additional government intervention.

[2] Crane-Droesch, Marshall, Rosch, Riddle, Cooper, and Wallander, 2019.
[3] Pryor, Scavia, Downer, Gaden, Iversion, Nordstrom, Patz, and Robertson, 2014.
[4] Real rates (net of inflation). The Billion-Dollar Disaster Event Costs data used in our model is Consumer Price Index (CPI) adjusted to 2020.

Figure 1

PROJECTED CHANGE IN HARVEST PRICE - CORN

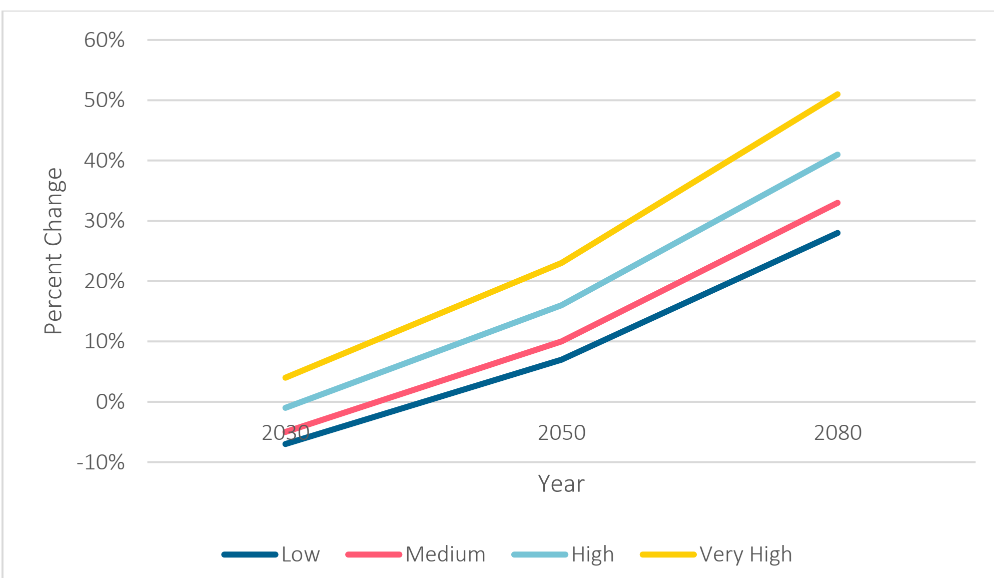


Data Source: NOAA (NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2021). https://www.ncdc.noaa.gov/billions/, DOI: 10.25921/stkw-7w73, NOAA National Centers for Environmental information, Climate at a Glance: Regional Time Series, published July 2021 https://www.ncdc.noaa.gov/cag/)

and USDA (as found in https://www.ag360insurance.com/crop-insurance-pricing/.)

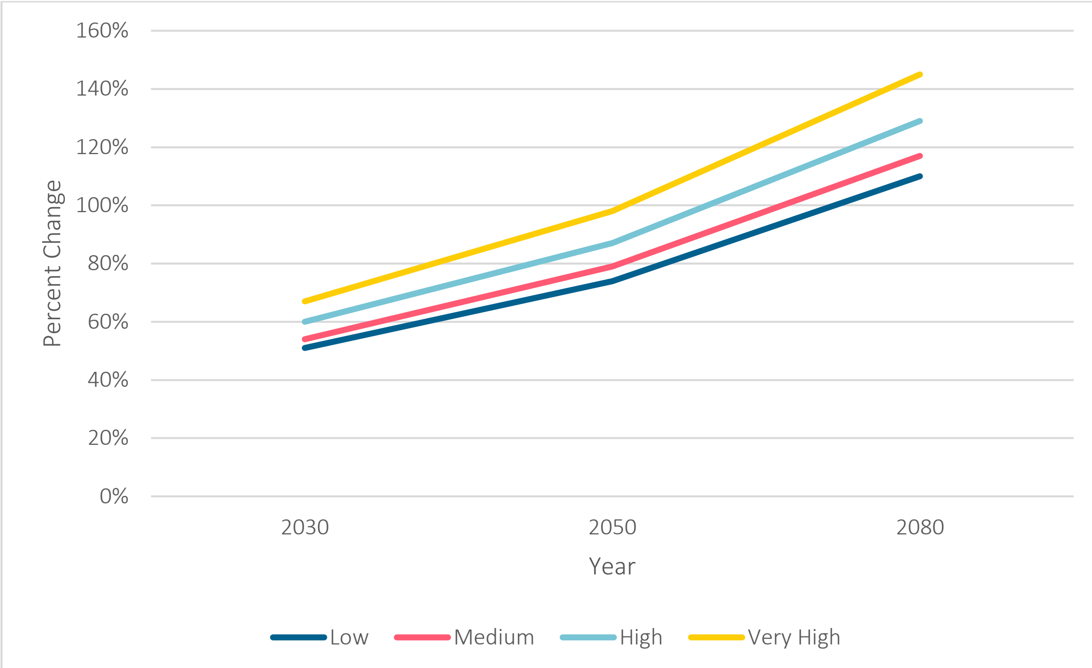
Figure 2

PROJECTED CHANGE IN HARVEST PRICE - SOY



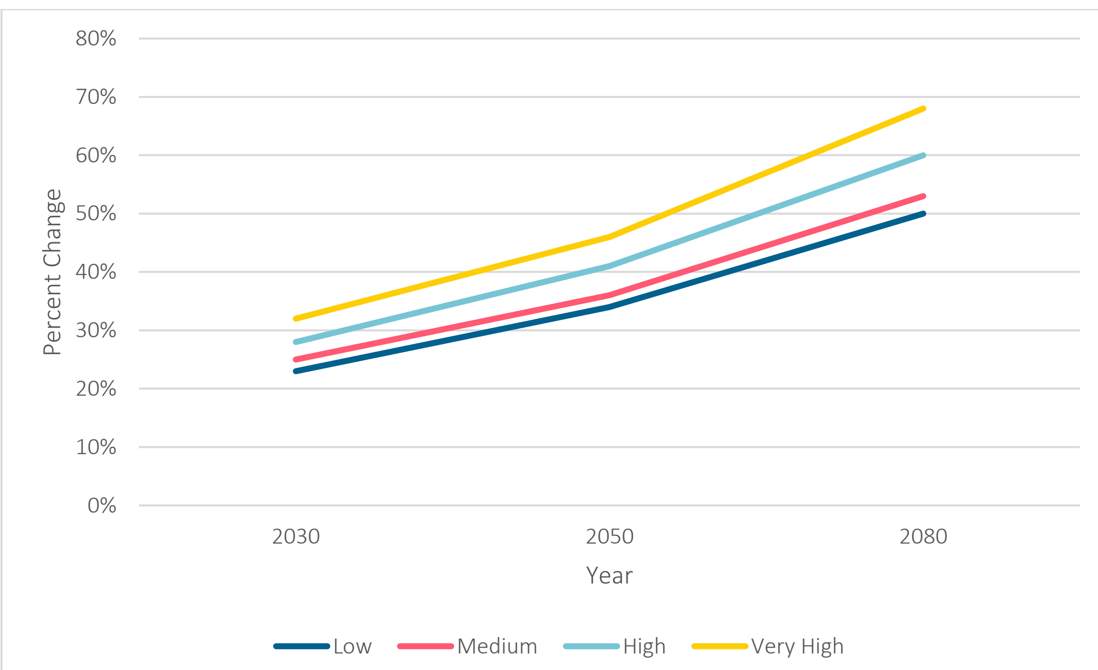
Data Source: NOAA and USDA.

Figure 3
PROJECTED CHANGE IN HARVEST PRICE – SPRING WHEAT



Data Source: NOAA and USDA.

Figure 4
PROJECTED CHANGE IN HARVEST PRICE – WINTER WHEAT



Data Source: NOAA and USDA.

The researchers also reviewed the National Association of Insurance Commissioners ("NAIC") Climate Risk Disclosure Report[5]. Several states require annual disclosures from large insurers related to climate risk. Based on the disclosure report, reported engagement in climate-related activities has increased since the survey has been collected starting in 2010. The insurance industry faces potentially significant impacts from the escalating effects of climate change due to its exposure to weather-related risks.

Adaptation methods such as shifting locations and methods of production have the potential to mitigate the risk of lower and volatile crop yields over time[6]. Expected crop yields are projected to improve with better irrigation and lower greenhouse gas concentration scenarios.

[5] Groshong, Czajkowski, Harms, Zhang, and Dahman, 2020.
[6] Crane-Droesch, Marshall, Rosch, Riddle, Cooper, and Wallander, 2019.

Background

The Insurance Information Institute provides a comprehensive overview on crop insurance[7]:

> *Agricultural production is subject to many uncertainties, including natural disasters. Adverse weather, insect infestations and plant diseases can severely reduce the yield or quality of a crop, wiping out a farmer's profits for the whole year in a bad season.*
>
> *Crop insurance is purchased by agricultural producers, including farmers, ranchers and others to protect against either the loss of their crops due to natural disasters, or the loss of revenue due to declines in the prices of agricultural commodities.*
>
> *The catastrophic potential of many crop-related perils led to the development of two types of crop insurance: multiple peril crop insurance (MPCI) and crop-hail insurance. Crop-hail insures against crop damage caused by hail and may also include extended coverages like fire and lightning. MPCI covers loss of crop value due to all types of natural disasters, including hail, drought, excessive moisture and unusually hot weather.*
>
> *Crop-hail policies are provided directly to farmers by private insurers and can be purchased at any time during the growing season. MPCI policies must be purchased prior to planting and are sold under the Federal Crop Insurance Program's unique public-private partnership. There are currently 13 private companies authorized by the United States Department of Agriculture Risk Management Agency (USDA RMA) to write MPCI policies.*
>
> *Providing crop insurance has historically been a difficult undertaking. Insurance operates most effectively when the pool of people exposed to a certain kind of risk do not all suffer a loss at the same time. For example, offering fire insurance works well because it is highly unlikely that every policyholder will suffer a fire at the same time. But if all policyholders are exposed to the same loss at the same time, such as if a flood affects all farmers in a floodplain, then insurers cannot spread the risks broadly enough and over a sufficient length of time to keep insurance affordable. The difficulty in spreading risks for crop-related risks is a fundamental issue that is critical to understanding the history of crop insurance and is one of the reasons for the creation of a federal crop insurance program.*

[7] Insurance Information Institute, 2021. Background on: Crop Insurance | III

Section 1: Introduction

The Society of Actuaries ("SOA") sponsored this research study (hereafter "the Study") to investigate projected changes in insurability and affordability of crop insurance coverages due to climate change. The researchers carried out the main objectives of this project, including background research, reviewing case studies, performing analysis on top crop insurers within the U.S, and developing this report. The objectives of the Study were the following:

1. Identify major studies regarding the impact of climate change on crops and the associated implications for pricing of crop insurance and/or secondary implications on availability of adequate food sources in areas dependent on the crops.
2. Analysis of the studies identified to determine overall trends in how climate change has impacted crops and availability and affordability of crop insurance, with a focus on the Midwest.
3. Deeper dive case study analysis to understand the impact of specific climate events on a deeper level, including but not limited to how various types of climate events impacted crops, Changes in the availability and cost of crop insurance for the geographic area subsequent to the climate event(s), and innovations in crop insurance coverage that helps mitigate the climate risk on crop insurance.
4. Complete a report summarizing conclusions, including overall impacts of climate change on crops and the associated impacts on availability and affordability of crop insurance.

Based on the results of the research, case studies and company analyses, the researchers have summarized the analyses, information gathered, and the resulting conclusions.

Section 2: Methodology

This section provides some information about the methodology and approach used to conduct this research.

2.1 INITIAL RESEARCH

The researchers conducted an initial literature review on the impact of climate change on agricultural productivity, and the resulting impact of the changes in the agricultural productivity on the affordability and availability of crop insurance. The literature used for this purpose is included in the References section of this report.

2.2 ANALYSIS

Upon completion of the initial research, the researchers performed a more detailed review for some of the initial research papers, and also reviewed additional research papers. The information from the more detailed review was used as the basis for our projection of the potential impact of climate risk on crop productivity, along with potential implications for the affordability and availability. See Section 3 for further details on this analysis.

Section 3: Summary of Research Results

Our findings from the research performed are summarized in the sections that follow based on certain key themes that were identified. Italics indicate direct quotes taken from a research paper.

3.1 IMPACT OF CLIMATE CHANGE AND EXTREME WEATHER ON U.S. AGRICULTURAL PRODUCTIVITY

3.1.1 GLOBAL CIRCULATION MODELS

According to the "Climate Change[8] and U.S. Agriculture: The Impacts of Warming and Extreme Weather Events on Productivity, Plant Diseases, and Pests[9][10]" article, *a changing climate[11] is likely to bring changing patterns of climate variability[12]*. Scientists have employed mathematical models known as Global circulation models (GCMs) to assess the earth's climate system, as it is too large to allow controlled experiments. GCMs predict:

- *High latitudes and high elevations are likely to continue to experience greater warming than the global mean warming (especially in winter).*
- *Winter and nighttime temperatures (minimum temperatures) are projected to continue to rise disproportionately.*
- *The hydrological cycle is likely to further intensify, bringing more floods and more droughts.*
- *More winter precipitation is projected to fall as rain rather than snow, decreasing snowpack and spring runoff, potentially exacerbating spring and summer droughts.*

3.1.2 EXTREME WEATHER EVENTS

Also, according to the "Climate Change and U.S. Agriculture: The Impacts of Warming and Extreme Weather Events on Productivity, Plant Diseases, and Pests" article, potential impacts of climate change on agriculture are expected to be based not only on the mean values of expected climatic parameters but also on the probability, frequency, and severity of extreme events. Small changes in mean temperature disproportionately change extreme event frequency. For example, the 20 days per year above 90°F experienced in the Corn Belt of Des Moines, Iowa, would double with a mean temperature increase of 3.6°F. Similarly, the irrigated cotton growing area of Phoenix, Arizona, would be expected to experience an increase from 90+ days above 100°F to 120 days. Weather extremes (very high temperatures, torrential rains, and droughts) can affect yields and disease patterns. For example, droughts followed by torrential rains can impact soil water absorption, increasing flooding potential that creates conditions favoring fungal infestations of leaves, roots, and tuber crops. Extremes along with shifted timing of seasons may separate predator/prey relationships among species that are critical for pest/pathogen control and plant pollinator populations.

3.1.3 INCREASED TEMPERATURE

The "Climate Change and U.S. Agriculture: The Impacts of Warming and Extreme Weather Events on Productivity, Plant Diseases, and Pests" article also notes that extreme weather events can have either direct or indirect effects on crop yields. *Higher temperatures increase moisture stress on crops directly by*

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[8] An overall alteration of mean climate conditions.
[9] Any organism or microorganism that harms or kills crops and reduces the value of crops before and after harvest.
[10] Rosenzweig, Iglesias, Yang, Epstein, and Chivian, 2000.
[11] The prevalent pattern of weather observed over a prolonged period of time.
[12] Fluctuations about the mean.

increasing evapotranspiration as well as the atmospheric holding capacity for water vapor. An indirect feedback loop is created when higher temperatures hasten the breakdown of organic matter in soils, which in turn leads to lower soil organic matter levels, culminating in less soil-moisture retention and additional crop moisture stress. Crops respond negatively when the optimal temperature range of values is exceeded, causing a drop in yield. For example, temperatures above 36^{O}C cause a loss of corn pollen viability. Air temperatures ranging from 45-55^{O}C and occurring for longer than 30 minutes directly damage crop leaves in most environments, while 35-45^{O}C temperatures are damaging if they persist even longer. Damage to crops by high temperatures varies by developmental stage, with those occurring during reproductive development being particularly dangerous, such as corn at tasseling, soybean at flowering, and wheat at grain-filling (soybean appears to have the ability to recover from heat injuries because it grows continuously). Additional effects are shown in Table 1.

3.1.4 PRECIPITATION

Precipitation is also a significant factor in overall U.S. agricultural productivity. According to the "Climate Change and U.S. Agriculture: The Impacts of Warming and Extreme Weather Events on Productivity, Plant Diseases, and Pests" article:

> *The average surface temperature of the Earth has increased by about 1.0ºF over the last century (IPCC, 1996b). The warming in North America is most pronounced in the Northeast, the Lake States, and most of the Western States (Figure 11) (T. Karl, NCDC, NOAA). At the same time, the annual precipitation has increased in most of the eastern portion of the U.S. and the Pacific Northwest (Figure 11). The winter minimum temperatures have increased disproportionately since 1950 in the North Central and Southwest regions (Figure 12).*
>
> *In the U.S., there is a trend to more days with heavy 24-hour precipitation totals (Figure 13) (Karl and Knight, 1998). Increases are largest for the Southwest, Midwest, and Great Lakes regions of the country. The interactions among the changes in temperature and precipitation are reflected in an increase in the area affected by severe wetness. The increase in wetness has had large impacts. Data from the National Climatic Data Center of NOAA show that the total area of the U.S. affected by extreme precipitation events has been increasing since 1910 (Figure 14). The cost of flood damage in the U.S. also appears to be increasing since 1970 (NOAA). The cost data are suggestive of changing climate regimes but are confounded by the increasing value of built infrastructure over the same time period.*
>
> *Although other factors, such as levels of inputs affect yields, we know that climate remains an important determinant of agricultural outcomes, especially when climatic events are severe. The relationship between corn yield and annual temperature and precipitation in Des Moines, Iowa, demonstrates this (Figure 17). Corn yields decline with warmer temperatures due to acceleration of the crop's development, especially during the grain-filling period. Greater precipitation (if not excessive) during the growing season tends to increase yields, as expected.*
>
> *U.S. crop prices have been strongly influenced by policy, as shown by the stable yet low prices for crops during the period of price supports from 1954 to 1970, and the greater yet more variables price since price supports were removed in the early 1970s. Crop prices have risen over the period 1950-1998, but with greater year-to-year fluctuations in terms of percent change from the previous year especially since 1970 (Figure 16). Prices are more variable in the recent period, 1971-98, than in the earlier period, 1950-70. Corn, soybean, and wheat prices in the recent period are more than four times more variable than during the 1950-1970 period (Table 4.).*

Figure 23 shows projected changes in U.S. wheat yield for the Hadley Center and Canadian Climate Centre climate change scenarios for the 2030s. Climate scenarios are based on projected mean monthly changes and not changes in variability. The direct effects of higher CO2 levels on crops are taken into account because higher carbon dioxide increases the rate of photosynthesis and improves water-use efficiency in crops (Acock and Allen 1985; Cure and Acock, 1986; Kimball, et al., 1995). Results show that some regions may improve production, while others suffer yield losses. This could lead to shifts of agricultural production zones around the nation. Furthermore, different crops will be affected differently, leading to the need for adaptation of supporting industries and markets.

3.1.5 REGIONAL DIFFERENCES

According to "Impacts of Climate Change and Extreme Weather on U.S. Agricultural Productivity: Evidence and Projection[13]":

This paper employs a stochastic frontier approach to examine how climate change and extreme weather affect U.S. agricultural productivity using 1940-1970 historical weather data (mean and variation) as the norm. We have four major findings. First, using temperature humidity index (THI) load and Oury index for the period 1960-2010 we find each state has experienced different patterns of climate change in the past half century, with some states incurring drier and warmer conditions than others. Second, the higher the THI load (more heat waves) and the lower the Oury index (much drier) will tend to lower a state's productivity. Third, the impacts of THI load shock and Oury index shock variables (deviations from historical norm fluctuations) on productivity are more robust than the level of THI and Oury index variables across specifications. Fourth, we project potential impacts of climate change and extreme weather on U.S. regional productivity based on the estimates. We find that the same degree changes in temperature or precipitation will have uneven impacts on regional productivities, with Delta, Northeast, and Southeast regions incurring much greater effects than other regions, using 2000-2010 as the reference period.

3.1.6 ADAPTATION

The "Climate Change and U.S. Agriculture: The Impacts of Warming and Extreme Weather Events on Productivity, Plant Diseases, and Pests" article also noted:

National farm policy can be a critical determinant in the adaptation of the farming sector to changing conditions. In the U.S., farm subsidies may either help or hinder necessary adaptation to the eventuality of a changing climate. An important policy consideration is the assessment of risk due to weather anomalies. If flood and drought frequencies increase as projected, the need for emergency allocations will also increase. Anticipating the probability and the potential magnitude of such anomalies can help make timely adjustments that may reduce social costs.

Beyond national boundaries, changes in the global patterns of supply and demand may have far-reaching consequences. Figure 24 shows projections of average national crop yield changes around the world for one climate change scenario. At high latitudes, warmer temperature may benefit crops that are currently limited by cold temperature and short growing seasons. In mid-latitudes, however, increased temperatures are likely to exert a negative influence on yields through shortening of crop development stages. In the low latitudes, growing periods for crops are

[13] Wang, Ball, Nehring, Williams, and Chau, 2017.

accelerated and heat and water stresses are exacerbated, resulting in steeper yield decreases than at mid and high latitudes, notwithstanding the potential beneficial physiological effects of atmospheric CO2 enrichment.

To explore the effects of changes in daily climate variability, tests of changes in temperature and precipitation variability on corn and soybean have been made using crop growth models at Des Moines, Iowa (Figure 25). If variability in temperature or precipitation is doubled, decreases in corn yields and increases in corn crop failures result. The corn crop failures for doubled temperature variance are due to slowed grain-filling that extended the corn growing period into frost episodes. Doubled precipitation variance causes water deficit failures in the corn crop. Halving precipitation variability results in an increase in mean yield and a large drop in the variability of the corn yields year-to-year.

For soybean, results of changing the variability of temperature and precipitation are similar to corn in direction yet greater in magnitude. A two-fold increase in the variability of temperature and precipitation results in large decreases in yields. Soybean crop failures increase when temperature is more variable, due to cold temperatures at the beginning and end of the crop season. When precipitation is more variable, the drop in yields is due to increased water deficits. With less precipitation variability (decreasing by half) there is a large positive effect on both corn and soybean crop yields, while the yields are less sensitive to halving temperature variability. Increased climate variability results in higher variability in crop yields.

3.1.7 CONCLUSIONS – IMPACT OF CLIMATE CHANGE ON U.S. AGRICULTURAL PRODUCTIVITY

Climate change is likely to bring changes in the patterns of climate events as well as changes in the mean. ***If temperature variability increases, crops growing at both low and high mean temperatures could be adversely affected since diurnal and seasonal canopy temperature fluctuations often exceed the optimum range. If temperature variability diminishes, however, crops growing near their optimum ranges might benefit.*** *Increases in daily temperature variability can reduce wheat yields due to lack of cold hardening and to resultant winterkill. Extremes of precipitation, both droughts and floods, are detrimental to crop productivity under rainfed conditions. Drought stress increases the demand for water in irrigated regions.*

3.2 HISTORICAL IMPACT OF CLIMATE CHANGE TO COST OF THE FEDERAL CROP INSURANCE PROGRAM

According to the “Climate Change Projected To Increase Cost of the Federal Crop Insurance Program due to Greater Insured Value and Yield Variability[14]” article:

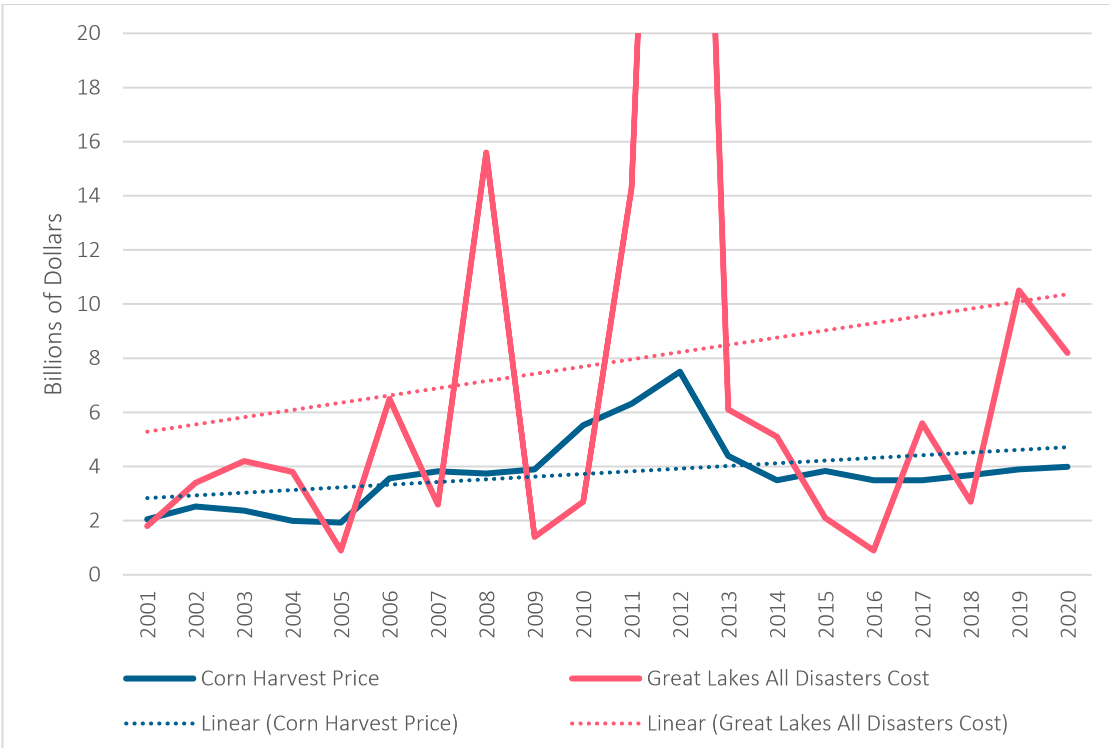
The cost of administering the FCIP rises in years with adverse weather events, such as droughts, when insurance claims outpace premiums paid for insurance coverage. Premiums are adjusted over time based on recent claim payout histories. As the frequency of adverse weather events changes, so do premiums. Climate change could affect the Federal Government’s fiscal exposure from the FCIP as premiums and subsidies adjust with changing growing conditions. Adverse weather could make yields more variable from year to year, causing losses to happen more frequently. Commodity prices could become more variable if adverse weather events affect large proportions of farmland at the same time, also increasing the frequency of crop insurance losses.

[14] Crane-Droesch, Marshall, Rosch, and Wallander, 2019.

Finally, declining supply could raise average commodity prices, causing increased payouts when losses occur, and therefore also raising premiums and subsidies.

Based on the information above, the cost of administering the FCIP rises in years with adverse weather events, when claims outpace premiums. For example, the following chart shows the cost of the Great Lakes Region extreme events over time compared to the FCIP price for Corn (note that 2012 has a total cost of $59.6 Billion, which is not shown entirely on the chart and is driven by Superstorm Sandy):

Figure 5
FCIP CORN COST



Data Source: NOAA and USDA.

The "Climate Change Projected To Increase Cost of the Federal Crop Insurance Program due to Greater Insured Value and Yield Variability" article also noted:

The estimated increase in FCIP costs is driven primarily by increasing commodity prices, followed by increasing yield risk. Results show that price risk is likely to decline for some crops under climate change, as the models suggest that average prices would increase faster than price volatility.

The following bullet points chart the key drivers of the increase in the FCIP, as mentioned in the article:

- Adverse weather → more variable year-to-year yields → higher loss frequency
- Adverse weather events → affect large proportions of farmland simultaneously → more variable commodity prices → higher loss frequency
- Declining supply → raised average commodity prices → increased loss occurrence payouts → raised premiums and subsidies

3.3 FUTURE IMPACT OF CLIMATE CHANGE TO COST OF THE FEDERAL CROP INSURANCE PROGRAM

RRC reviewed the "Climate Change and Agricultural Risk Management Into the 21st Century[15]" report which provided futuristic insights and quantification of how climate change could affect the cost of U.S. agricultural risk management programs toward the end of the 21st century. The approach of the paper was to first assess the impact of climate change on yields, then quantify the implications of yield change on production and prices, which in turn affects the cost of the FCIP program. This is done through a system of chained models, integrating agronomic, economic, and policy models with statistical/machine learning tools. These models are combined to provide joint projections of yields, acreages, and prices, which allowed the team to project the costs of present levels of coverage in the FCIP for the year 2080, which was taken as a representative year for the second half of the 21st century in the paper. The research focused on corn, soybeans, and winter wheat, three crops that make up 55 percent of agricultural land use, but 65 to 75 percent of the total premium subsidy costs of the FCIP.

The "Climate Change Projected To Increase Cost of the Federal Crop Insurance Program due to Greater Insured Value and Yield Variability" article also noted that the Economic Research Center (ERS) used weather simulations from climate models to project how yields and yield variability might respond to climate change in 2080, and then used an economic model to translate those changes in yield into changes in crop production and crop prices. The two scenarios posed were one where farmers can adapt by adjusting planting behavior to adapt to changes in yield, and one where farmers cannot adapt. The study also compared two climate scenarios with different projections of greenhouse gas emissions levels to a hypothetical future. The cost of today's Federal Crop Insurance Program would increase by the following percentages under the four scenarios:

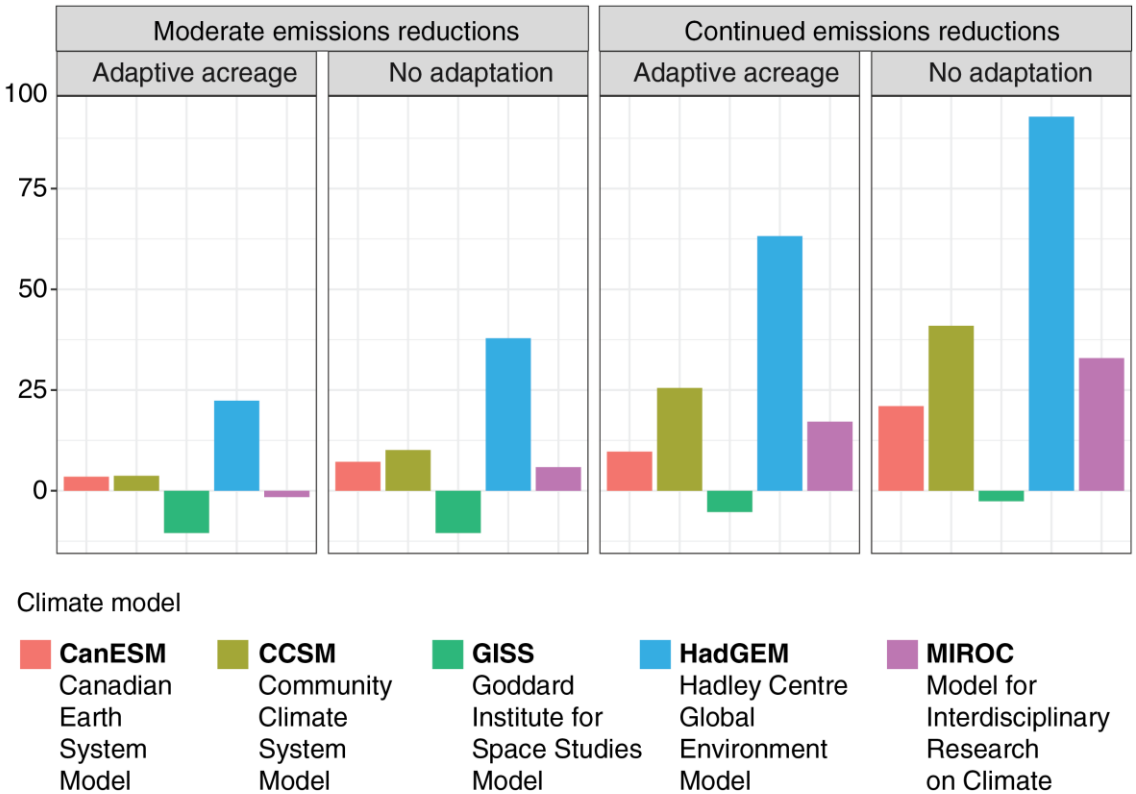
- Moderate emissions reductions and farmer adaptation: 3.5%
- Moderate emissions reductions and no farmer adaptation: 10%
- Continued emissions reductions and farmer adaptation: 22%
- Continued emissions reductions and no farmer adaptation: 37%

Increasing commodity prices is the main driver of the estimated increase in FCIP costs, followed by increasing yield risk[16]:

[15] Crane-Droesch, Marshall, Rosch, Riddle, Cooper, and Wallander, 2019.
[16] Crane-Droesch, Marshall, Rosch, and Wallander, 2019.

Projected changes to the cost of the Federal Crop Insurance Program varies with the climate model and emissions scenario

Projected percent change in cost of premium subsidies



Note: Groupings represent scenarios in which climate change adaptation does and does not occur (no adaptation versus adaptive acreage) and differing projections of greenhouse gas emissions levels. Bars represent different climate models used in the analysis, shown individually to show the variability across models.
Source: USDA, Economic Research Service calculations using data from various sources.

USDA Economic Research Service. November 4, 2019. https://www.ers.usda.gov/amber-waves/2019/november/climate-change-projected-to-increase-cost-of-the-federal-crop-insurance-program-due-to-greater-insured-value-and-yield-variability/

3.4 CASE STUDY SPOTLIGHTING THE MIDWEST

We researched variables that we believed would predict the target variables of Base Price[17] and Harvest Price[18] of the FCIP for three major crops (Corn, Soybean, and Wheat) from 2001-2020. The data we gathered from the National Oceanic and Atmospheric Administration (NOAA)[19][20] included:

- Maximum Temperature (1-Month Time Scale of the month used as the average daily settlement price) based on the Farm Credit Services of America. For example, the Harvest Price for Corn is based on the October average daily settlement price, so the average Maximum Temperature for the month of October in each year is used here. All other variables for Corn are based on the month of October. Similarly, Soybean variables are based on October as well. Spring Wheat variables are based on August and Winter Wheat variables are based on July. These months were determined based on when the different crops are harvested.
- Precipitation (1-Month Time Scale approach stated above used).
- Palmer Drought Severity Index (PDSI)[21]: attempts to measure the duration and intensity of the long-term drought-inducing circulation patterns. Long-term drought is cumulative, so the intensity of drought during the current month is dependent on the current weather patterns plus the cumulative patterns of previous months. Since weather patterns can change almost literally overnight from a long-term drought pattern to a long-term wet pattern, the PDSI can respond fairly rapidly.
- Palmer Hydrological Drought Index (PHDI): measures hydrological impacts of drought (e.g., reservoir levels, groundwater levels, etc.) which take longer to develop and longer to recover from. This long-term drought index was developed to quantify these hydrological effects, and it responds more slowly to changing conditions than the PDSI.
- Palmer Modified Drought Index (PMDI): operational version of the PDSI. A full description is available in Heddinghaus and Sabol (1991).
- Palmer Z Index: measures short-term drought on a monthly scale.
- Billion-Dollar Disaster Event Counts (CPI Adjusted to 2020).
- Billion-Dollar Disaster Event Costs (CPI Adjusted to 2020).

All predictive variables with the exception of the Billion-Dollar Disaster Event variables are grouped into respective crop regions (Crop Belt, Soybean Belt, and Winter Wheat Belt/Spring Wheat Belt). Billion-Dollar Disaster Event data has been grouped into the following regions:

- Great Lakes States Region (IL, IN, MI, MN, OH, PA, NY, WI),
- Central Climate Region (IL, IN, KY, MO, OH, TN, WV), and
- East North Central Climate Region (IA, MI, MN, WI).

According to the research article "U.S. Billion-dollar Weather and Climate Disasters: Data Sources, Trends, Accuracy and Biases[22]" regarding the loss data that NOAA uses:

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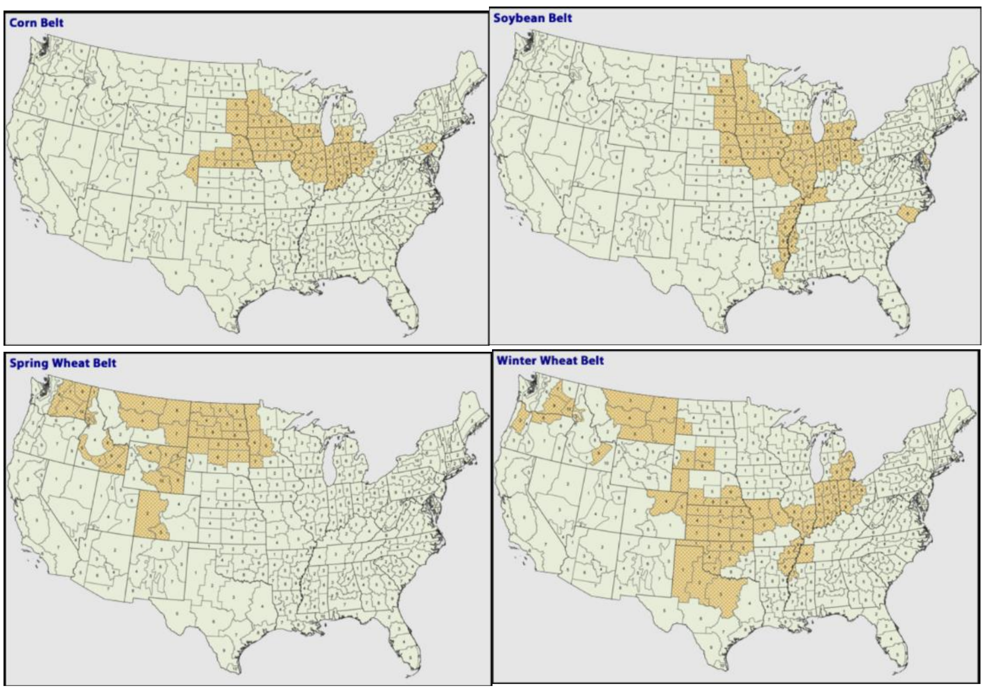
[17] The insurance price projected just before planting time. What Is The Harvest Price Option, And Why Do Farmers Need To Have That Choice?
[18] The Harvest Price Option is revenue or price coverage within the crop insurance policy that provides protection on lost production at the higher of the price projected just before planting time or the price at harvest. Projected price is just an estimate of the final price, per se and farmers pay an additional premium for this type of price protection. It is similar to the concept of paying an indemnity at "replacement value," similar to what is available for homeowners insurance. It enables the producer to acquire the lost production at its replacement cost. What Is The Harvest Price Option, And Why Do Farmers Need To Have That Choice?
[19] NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2021).
[20] NOAA National Centers for Environmental information, Climate at a Glance: Regional Time Series, published July 2021.
[21] https://www.ncdc.noaa.gov/temp-and-precip/drought/historical-palmers/overview
[22] Smith and Katz, 2013.

Disaster types include tropical cyclones, floods, droughts / heat waves, severe local storms (e.g., tornado, hail, straight-line wind damage), wildfires, crop freeze events and winter storms. These loss estimates reflect direct effects of weather and climate events (i.e., not including indirect effects) and constitute total losses (i.e., both insured and uninsured). The insured and uninsured direct losses include: physical damage to residential, commercial and government/municipal buildings, material assets within a building, time element losses (i.e., time-cost for businesses and hotel-costs for loss of living quarters), vehicles, public and private infrastructure, and agricultural assets (e.g., buildings, machinery, livestock).

The regional breakdowns for the Corn Belt, Soybean Belt, Winter Wheat Belt, and Spring Wheat Belt are shown below[23]:



NOAA's website described the increasing trend of high-cost disasters:

The number and cost of weather and climate disasters are increasing in the United States due to a combination of increased exposure (i.e., more assets at risk), vulnerability (i.e., how much damage a hazard of given intensity—wind speed, or flood depth, for example—causes at a location), and the fact that climate change is increasing the frequency of some types of extremes that lead to billion-dollar disasters (NCA 2018, Chapter 2).

It is important to keep in mind that these estimates do not reflect the total cost of U.S. weather and climate disasters, only those associated with events in excess of $1 billion in damages. However, these extreme events do account for the majority (>80%) of the damage from all recorded U.S. weather and climate events (NCEI; Munich Re), and they are becoming an

[23] https://www.ncdc.noaa.gov/monitoring-references/maps/us-ag-belts.php

increasingly larger percentage of the total damage costs from weather-related events at all scales and loss levels.

In particular, the historically large U.S. losses from hurricanes and wildfires over the last four years (2017-2020) have further skewed the total distribution of extreme weather costs. From 1980-2000, about ***75%*** *of all disaster-related costs were due to billion-dollar disasters, and by 2010, the percentage had risen to about* ***80%****. By 2020, it had risen again to about* ***85% of all disaster-related costs****, or $1.875 trillion out of $2.215 trillion.*

We also chose to focus this case study on the Midwest Region (from "Climate Change Impacts in the United States – Chapter 18 – Midwest[24]"):

In 2011, 11 of the 14 U.S. weather-related disasters with damages of more than $1 billion affected the Midwest. Several types of extreme weather events have already increased in frequency and/or intensity due to climate change, and further increases are projected. ***The Midwest region accounts for about 65% of U.S. corn and soybean production****, mostly from non-irrigated lands.* ***Corn and soybeans constitute 85% of Midwest crop receipts****, with high-value crops such as fruits and vegetables making up most of the remainder, Corn and soybean yields increased markedly (by a factor of more than 5) over the last century largely due to technological innovation, but are still vulnerable to year-to-year variations in weather conditions.*

We began by running a regression on Billion-Disaster Event Costs as the predictor variable and using Base Price and Harvest Price as target variables. We found that this predictor variable had a stronger relationship in predicting Harvest Price (based on R-squared), which led us to deepen our focus on this target variable. For Corn and Soybean, we used the Great Lakes States as opposed to the Central Region as this produced a better R-squared. For Winter Wheat and Spring Wheat, it was the opposite, and the Central Region produced a higher R-squared. The highest R-Squared value was 0.852 based on using all variables with Corn. However, to avoid overfitting the models and using too many variables, we performed several iterations and determined that the models of best fit are as follows:

- Corn
  - Variables:
    - Great Lakes States Billion-Dollar Event Costs
    - PHDI
    - PMDI
  - 0.755 R-Squared[25]
  - P-values[26] all under 0.005
- Soybean

[24] Pryor, Scavia, Downer, Gaden, Iversion, Nordstrom, Patz, and Robertson, 2014.
[25] R-squared (R^2) is a statistical measure that represents the proportion of the variance for a dependent variable that's explained by an independent variable or variables in a regression model. Whereas correlation explains the strength of the relationship between an independent and dependent variable, R-squared explains to what extent the variance of one variable explains the variance of the second variable. So, if the R^2 of a model is 0.60, then approximately sixty percent of the observed variation can be explained by the model's inputs. R-Squared Definition
[26] A statistic closely related to the standard error (and indeed derived from the standard error) is the p-value. For a given coefficient estimate, the p-value is an estimate of the probability of a value of that magnitude (or higher) arising by pure chance. For example, suppose a certain variable in our model yields a coefficient of 1.5 with a p-value of 0.0012. This indicates that, if this variable's true coefficient is zero, the probability of getting a coefficient of 1.5 or higher purely by chance is 0.0012.3 In this case, it may be reasonable to conclude: since the odds of such a result arising by pure chance is small, it is therefore likely that the result reflects a real underlying effect—that is, the true coefficient is not zero. Such a variable is said to be significant. On the other hand, if the p-value is, say, 0.52, it means that this variable—even if it has no effect—is much more likely to yield a coefficient of 1.5 or higher by chance; as such, we have no evidence from the model output that it has any effect at all. Note that this is not to say that we have evidence that it has no effect—it may be that the effect is actually there, but we would need a larger dataset to "see" it through our model. Generalized Linear Models For Insurance Rating Second Edition, Casualty Actuarial Society

  - Variables
    - Great Lakes States Billion-Dollar Event Costs
    - PHDI
    - PMDI
  - 0.561 R-Squared
  - P-values all under .040
- Winter Wheat
  - Variables
    - Central Region Billion-Dollar Event Costs
    - PHDI
    - PMDI
  - 0.375 R-Squared
  - P-Values all under 0.105
- Spring Wheat
  - Variables
    - Central Region Billion-Dollar Event Costs
    - PDSI
    - PMDI
  - 0.454 R-Squared
  - P-Values all under 0.060

3.4.1 MODEL CONCLUSIONS

In conclusion based on our analysis these variables do show that they have predictive power with respect to estimating crop prices. The models fit better with harvest price instead of base price. The variables did not show the same strength for each crop. For example, Spring Wheat had a greater fit using PDSI vs. PHDI. Additionally, the Great Lakes States Region was more predictive for Corn and Soybean while the Central Region had a better fit to the Spring Wheat and Winter Wheat data. Overall, the model with the best fit was related to Corn harvest prices, as evidenced by the highest R-squared statistic. Conversely, the model with the worst fit was related to Winter Wheat harvest prices, as seen by the lowest R-squared statistic. These models predict what might happen with crop prices, which has a direct impact on affordability and availability of crop insurance. As we continue to see costly disasters on the rise, crop insurance prices may increase as well. Fortunately, innovations are being undertaken to mitigate the impact that climate change is having on crops and crop insurance throughout the U.S.[27]

3.4.2 FORECAST

Using our crop price model that predicts Harvest Price of the FCIP for three major crops (Corn, Soybean, and Wheat) from 2001-2020, we created a model forecast to predict prices in 2030, 2050, and 2080[28] below. Our approach was as follows:

- Project each variable in the model to the future year based on a linear trend. For example, Great Lakes States Billion-Dollar Disaster Costs were $8.2 billion in 2020[28]. Using a linear trend of the data from 2001-2020, this projects to $13.03 billion in 2030. We experimented with different trend lines but ultimately selected linear trend to coincide with our linear regression model and for simplicity.

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[27] See the Appendix A graphs that show an upward trend in both Billion-Dollar Event Costs and Harvest Prices
[28] Real rates (net of inflation). The Billion-Dollar Disaster Event Costs data used in our model is Consumer Price Index (CPI) adjusted to 2020

- Create future scenarios based on emissions reductions and farmer adaptation. We created four scenarios: “Low”, “Medium”, “High”, and “Very High”, and used simulation projections as relativities to adjust our different scenarios from the article “Climate Change Projected to Increase Cost of the Federal Crop Insurance Program due to Greater Insured Value and Yield Variability”. Our process for deriving these relativities is described on the next page, and we used the derived relativities to adjust the variables in our forecast model. We decided to apply these relativities to our variables instead of using the results directly in order to account for the potential variability in our model variables in the future and pose scenarios that show how crop prices could change based on changes in these variables at a more granular level. The article presents four scenarios in which the cost of today’s Federal Crop Insurance Program would increase by the following percentages (as previously noted on page 18)[29]:
    - Moderate emissions and farmer adaptation: 3.5%
    - Moderate emissions and no farmer adaptation: 10%
    - Higher emissions and farmer adaptation: 22%
    - Higher emissions and no farmer adaptation: 37%

  Our “Very High” scenario is where we make no adjustment to our variable coefficients, but instead use our projected variable as an input in the model. Our thought process was that we see this as our continued projection without any future emissions reduction or farmer adaptation. To create our relativities to adjust to the other scenarios, we used factors based on the article’s scenarios. For example, since the lowest projection is a 3.5% increase in FCIP prices and the highest projection is a 37% increase in FCIP prices, we calculated 1.035 / 1. 37 = 0.755 as our relativity. We then multiplied this relativity by the product of the original coefficients in our model and our projected variables. For example, recall our projected Great Lakes States Billion-Dollar Disaster Cost of $13.03 billion in 2030. Our coefficient for this variable in the corn model is 0.106396. Our coefficients for PHDI and PMDI are 1.495921 and -1.281039, respectively, and our projected variables for PHDI and PMDI in 2030 are 5.83 and 5.28, respectively. Our intercept coefficient in the model is 2.13087. Then for our Low scenario for corn we get: 0.755 * (13.03 * 0.106396 + 1.495921 * 5.83 - 1.281039 * 5.28) + 2.13087 = $4.66. We only applied the relativity once as opposed to each variable so as not to double count its effects. Overall results are below:

[29] The two scenarios posed were one where farmers can adapt by adjusting planting behavior to adapt to changes in yield (farmer adaptation), and one where farmers cannot adapt. The study also compared two climate scenarios with different projections of greenhouse gas emissions levels to a hypothetical future (moderate emissions and higher emissions).

Table 1
CORN FORECASTED HARVEST PRICES

Scenario (1)	2020 Harvest Price (2)	2030 Projected Harvest Price (3)	2050 Projected Harvest Price (4)	2080 Projected Harvest Price (5)	2030 Percent Change in Harvest Price (6) = ((3) / (2)) - 1	2050 Percent Change in Harvest Price (7) = ((4) / (2)) - 1	2080 Percent Change in Harvest Price (8) = ((5) / (2)) - 1
Low	$3.99	$4.66	$5.97	$7.95	17%	50%	99%
Medium	$3.99	$4.82	$6.21	$8.31	21%	56%	108%
High	$3.99	$5.11	$6.66	$8.99	28%	67%	125%
Very High	$3.99	$5.47	$7.22	$9.83	37%	81%	146%

Table 2
SOY FORECASTED HARVEST PRICES

Scenario (1)	2020 Harvest Price (2)	2030 Projected Harvest Price (3)	2050 Projected Harvest Price (4)	2080 Projected Harvest Price (5)	2030 Percent Change in Harvest Price (6) = ((3) / (2)) - 1	2050 Percent Change in Harvest Price (7) = ((4) / (2)) - 1	2080 Percent Change in Harvest Price (8) = ((5) / (2)) - 1
Low	$10.54	$9.77	$11.26	$13.50	-7%	7%	28%
Medium	$10.54	$10.01	$11.59	$13.97	-5%	10%	33%
High	$10.54	$10.44	$12.20	$14.83	-1%	16%	41%
Very High	$10.54	$10.98	$12.96	$15.92	4%	23%	51%

Table 3
SPRING WHEAT FORECASTED HARVEST PRICES

Scenario (1)	2020 Harvest Price (2)	2030 Projected Harvest Price (3)	2050 Projected Harvest Price (4)	2080 Projected Harvest Price (5)	2030 Percent Change in Harvest Price (6) = ((3) / (2)) - 1	2050 Percent Change in Harvest Price (7) = ((4) / (2)) - 1	2080 Percent Change in Harvest Price (8) = ((5) / (2)) - 1
Low	$4.44	$6.70	$7.74	$9.31	51%	74%	110%
Medium	$4.44	$6.84	$7.95	$9.61	54%	79%	117%
High	$4.44	$7.09	$8.32	$10.17	60%	87%	129%
Very High	$4.44	$7.41	$8.79	$10.87	67%	98%	145%

Table 4
WINTER WHEAT FORECASTED HARVEST PRICES

Scenario (1)	2020 Harvest Price (2)	2030 Projected Harvest Price (3)	2050 Projected Harvest Price (4)	2080 Projected Harvest Price (5)	2030 Percent Change in Harvest Price (6) = ((3) / (2)) - 1	2050 Percent Change in Harvest Price (7) = ((4) / (2)) - 1	2080 Percent Change in Harvest Price (8) = ((5) / (2)) - 1
Low	$4.44[30]	$5.45	$5.93	$6.65	23%	34%	50%
Medium	$4.44	$5.53	$6.04	$6.80	25%	36%	53%
High	$4.44	$5.68	$6.24	$7.09	28%	41%	60%
Very High	$4.44	$5.86	$6.49	$7.44	32%	46%	68%

Overall, based on our model forecasting we can conclude that prices are projected to increase well into the future, which will affect the availability and affordability of crop insurance. Three out of four crops show an increase in prices (the exception being soy), even under scenarios in which there is farmer adaptation and reductions in emissions. See Appendix A for additional background information.

[30] The FCIP only has one price for Wheat which is why the current Harvest Price shown is identical for Spring and Winter Wheat.

3.5 SUMMARY OF CHALLENGES ARISING FROM CLIMATE CHANGE

The "Climate Change and Agricultural Risk Management Into the 21st Century" article also noted:

> *Absent changes to program design, we find that the cost of one Federal agricultural risk management program, the FCIP, is likely to increase, driven by a combination of increasing overall variability of prices and yields, and higher prices driven by lower supply. Lower supply is due to yield changes that are imperfectly offset by acreage changes, driven by weather that is projected to be less favorable to field crops than a future without climate change, on average, over most of the United States.*

The "Climate Change and U.S. Agriculture: The Impacts of Warming and Extreme Weather Events on Productivity, Plant Diseases, and Pests" article also noted:

> *The combination of long-term change (warmer average temperatures) and greater extremes (heat spells, droughts and floods) suggest that climate change could have negative impacts on U.S. agricultural production. Economic losses in some U.S. agricultural regions could rise significantly due to greater climate variability, and to increases in insects, weeds, and plant diseases.*
>
> *Changes in agricultural zones and in productivity due to climate change (preferential warming at high latitudes) may lessen the comparative advantage that the U.S. now enjoys as a leading international exporter of major agricultural commodities.*

3.6 STEPS CURRENTLY TAKEN BY STATES TO MITIGATE THE IMPACTS OF CLIMATE CHANGE ON CROP INSURANCE

According to the NAIC Climate Risk Disclosure Data[31]:

> *The insurance industry faces potentially significant impacts from the escalating effects of climate due to its exposure to weather-related property risks, investment volatility, and other issues. Given the unprecedented challenges facing the insurance industry, effective climate risk disclosures will help regulators assess and evaluate insurance industry risks along with the potential for insurer actions to mitigate climate risk.*
>
> *In 2010, the NAIC membership adopted the Insurer Climate Risk Disclosure Survey as a way for state insurance regulators, insurance companies, investors, and consumers to identify trends, vulnerabilities, and best practices by collecting information about how companies assess and manage climate risk. The survey's eight questions cover topics including climate risk governance, climate risk management, modeling and analytics, stakeholder engagement and greenhouse gas management. About 1,200 companies participated in 2018.*
>
> *In this analysis, we used statistical methods to examine two main questions: 1) How do insurers across key characteristics assess and manage risks related to climate change? and 2) How have these responses changed over the past 10 years?*

The article "The Impacts of Climate Change and Extreme Weather on U.S. Agricultural Productivity: Evidence and Projection" also notes:

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[31] Groshong, Czajkowski, Harms, Zhang, and Dahman, 2020.

Over the long run, each state has gradually adapted to state-specific climate condition (the average level of temperature and precipitation, and the degree of weather fluctuations). It is the unexpected weather shocks (deviations from historical average variations of Oury index[32] and THI load[33]) that are affecting regional productivity more profoundly.

3.7 STEPS CURRENTLY TAKEN BY CROP INSURERS TO MITIGATE THE IMPACT OF CLIMATE CHANGE ON CROP INSURANCE

Findings from the NAIC Climate Risk Disclosure Data include the following:

- Reported engagement in climate-related activities has increased over the years that the survey has been collected
- Few insurers report altering their investment strategy in response to considerations of the impact of climate change on its investment portfolio
- But more than half of all companies report at least some engagement in enterprise-wide climate risk management
- A majority of insurers across every line of business reported similar levels of engagement with internal greenhouse gas management
- Opportunity exists to bring the survey into alignment with other climate risk disclosures and to increase the survey's usefulness

See the Appendix for the full survey questions and responses.

3.8 POTENTIAL FUTURE MITIGATIONS BY CROP INSURERS AND FARMERS

According to "Blockchain Climate Risk Crop Insurance[34]":

Blockchain Climate Risk Crop Insurance offers a different kind of crop insurance that's both affordable and accessible to smallholder farmers at scale. Each insurance policy is plugged into smart contracts on a blockchain[35] and indexed to local weather. During an extreme weather event, the policies are automatically triggered on the technology platform, which facilitates timely and fair pay-outs. Compared to traditional index-based insurance, this system is much faster and much more transparent, leading to reduced costs and increased trust for both farmers and insurers alike. The instrument relies on three main elements: 1. an insurance provider or, on its behalf, insurance service and a data provider; 2. a user interface; and 3. an application layer linking insurance policies to a blockchain. There are variations in the role and responsibilities for each of these components in the pilot phase and subsequent phases.

To estimate returns for the blockchain technology platform, we built a cashflow model based on the pilot, targeting 1.2 million maize farmers in Kenya for four years. We then ran a simulation for

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[32] An aridity index that combines temperature and precipitation information that can capture more impact on crop production than a single measure of temperature or precipitation.

[33] Temperature-humidity index (THI): A combined measure of temperature and relative humidity that has been shown to have significant impacts on livestock production.

[34] Micale and Caenegem, 2019.

[35] Blockchain or Distributed Ledger Technology (DLT) can be defined as a ledger of individual blocks of data, linked and secured through encryption technology (hashes). Copies of the ledger are stored on a distributed network and updated when a transaction occurs (Voshmgir and Kalinov, 2017).

four different scenarios reflecting increased degrees of integration of weather index crop insurance activities on the platform, which will unfold as the instruments moves from pilot to scale-up.

Key takeaways include:

- ***The initiative is profitable under all scenarios**, particularly during scale-up phase with an integrated insurance platform model (scenario B2), where return on investment may reach as much as 38%;*
- ***In the long term, an integrated insurance platform model (scenario B2) can reach up to 41% reduction of levelized costs needed to issue a policy**. This reduction can partly be transferred to the smallholder farmers in the form of a premium reduction of up to 30%.*

According to "FarmersEdge[36]":

Farmers Edge is a global leader in digital agriculture. Our mission is to create the world's most comprehensive digital platform to empower and connect stakeholders across the entire agricultural ecosystem. We're passionate about sustainable farming and put innovation at the forefront of everything we do. Together, we're leading the next agricultural revolution creating intelligent technologies to help farmers and their trusted advisors be more efficient and successful in improving how food is produced and distributed to a rapidly growing global population.

According to "Review of FSD's Index Based Weather Insurance Initiatives[37]":

In 2005, FSD Kenya began sector-wide support for the development of index-based agricultural insurance. The aim was to determine whether viable indexed products could be offered which would reduce the impact of weather-related losses. The idea is that effective insurance makes smallholder farmers and pastoralists less vulnerable to crises caused by weather, allowing greater access to credit and increased investment in agricultural production. FSD's engagement began by supporting the development of insurance products covering maize crops. Dry runs were conducted in three areas of Kenya. Since 2008, a number of live pilot studies have been conducted with the aim of developing a market for index insurance in collaboration with Kenya's insurance sector. FSD worked with a wide range of organisations and individuals in both private and public sector, together with the World Bank's Agricultural Risk Management Team (ARMT) and the International Livestock Research Institute (ILRI) as technical partners. The Rockefeller Foundation and the Department for International Development (DFID) were co-funders in the project. Four insurers were engaged in training and pilots during this phase of the project. Automated weather stations were established in several pilot areas in partnership with the Kenya Meteorological Department. Thirty-five insurance products were designed covering six types of agricultural products. These led to five separate payouts to insurance buyers.

In May 2012, FSD Kenya commissioned Bankable Frontier Associates (BFA) to conduct a review of the project and make recommendations for the next stage of the work. The review was to include:

- *Project performance.*
- *Identifying similar projects and highlighting lessons learned.*

[36] FarmersEdge, About the Company, 2021. https://www.farmersedge.ca/
[37] Bankable Frontier Associates, 2013.

- *Draw comparisons with products developed under the IBWI (Index Based Weather Insurance) project in terms of appropriateness, pricing, methodologies and commercial potential.*

The purpose of the review was to assess the impact of the project on market development and gauge the viability of creating a functioning, sustainable market for agricultural index insurance.

Between May and September of 2012, interviews were conducted with 34 insurance industry players in Kenya and beyond. In addition, focus group discussions and in depth interviews were held with 97 farmers and pastoralists who had taken part in the various pilot programs across the country. ***The picture that emerged from the review [suggests that] while FSD has done an admirable job in bringing stakeholders onboard and executing pilots, and while strong demand and impact potential clearly exist, there remain substantial challenges to establishing viable index insurance for smallholder farmers on a retail basis at scale.***

FSD's IBWI initiative has, like many similar pilots, focused on what Porteous (2005) calls the, "supra-national market zone", concentrating on retail index initiatives. This approach deflected attention from addressing some of the fundamental building blocks required for building a market. These include, for example, improved access to inputs, husbandry and irrigation, ensuring reliable access to weather data, and a supportive regulatory framework. While these may have limited immediate or direct impact on poverty reduction, it is unlikely that insurers can take existing retail pilots to scale without them.

We recommend that FSD scale down the retail pilots and take a longer-term view. For example, we suggest they concentrate on meso- and macro- level cover, such as agricultural lending portfolio or area drought cover for NGOs or government agencies responsible for drought response. Further pilots ought to focus on those insurers who have the greatest interest and capacity to engage in this kind of insurance. In addition, an experimental approach should be taken to test the viability of satellite use for product design and payout triggering. Innovative and cost-effective client communication strategies need to be developed and incentive structures put in place. These should be sufficiently attractive for the range of players involved in the value chain approach to insurance delivery for both IBCI (Index Based Crop Insurance) and IBLI (Index Based Livestock Insurance).

3.9 IMPLICATIONS OF THE CHALLENGES TO AFFORDABILITY AND AVAILABILITY OF INSURANCE

According to the research, individual states' productivity is strongly affected by its state specific characteristics such that even with similar weather patterns and natural resources productivity can differ significantly.

The "Climate Change Impacts in the United States – Chapter 18 – Midwest" articles also notes:

In the next few decades, longer growing seasons and rising carbon dioxide levels will increase yields of some crops, though those benefits will be progressively offset by extreme weather events. Though adaptation options can reduce some of the detrimental effects, in the long term, the combined stresses associated with climate change are expected to decrease agricultural productivity.

3.10 NEXT STEPS

According to the recent article "Wild Weather Plagues North America Grain Crops as Demand Surges[38]":

> *The U.S. and Canada are seeing unusual variability in climate, with some crops withering from severe heat and drought while others see flooding. Meanwhile, demand is surging as economies recover from the coronavirus pandemic, so much so that every grain counts.*
>
> *The culprit is an abnormal, high pressure system that's likely to remain in place during a key period of the growing season when plants are blooming and developing. It's responsible for the hottest temperatures ever in the U.S. Pacific Northwest while forming a trough across the central U.S. that's bringing rain showers. The hot and arid conditions have moved east, spilling over into farming areas in the U.S. Plains and Canadian Prairies, hurting everything from spring wheat that goes into pizza to canola used for cooking oil.*
>
> *…In the past, both drought and rainfall would normally be milder and more widespread. But the world's climate is changing and getting more extreme, resulting in pockets of lushness and harsh dryness. Crop conditions in parts of the Midwest and mid-South regions are near-ideal.*
>
> *Some farming towns in southern Minnesota, a major grower of wheat, corn and soybeans, are seeing the least rain since 2012 and the hottest temperatures in over a decade. In neighboring North Dakota, conditions of the spring wheat crop are the worst since 1988 in government data.*

The Bloomberg article graphs the spread between 2021 good/excellent ratings and five-year averages for top-growing spring wheat states North Dakota and Montana and shows that both states rate far below their five-year averages, with North Dakota down 48% and Montana down 38%, respectively, as of the end of June 2021.

Even today in 2021, climate variability is increasing rapidly, and the even more extreme climate change we are experiencing is exacerbating the crop affordability and availability issue.

Section 4: Concluding Remarks

4.1 CONCLUSION

Based on the research, absent changes to program design, the cost of the FCIP is likely to increase, driven by a combination of increasing overall variability of prices and yields, and higher prices driven by lower supply[39]. Future crop yields are expected to be more strongly influenced by anomalous weather events than by changes in average temperature or annual precipitation[40]. Significant variation in impacts of climate change were observed by crop and between geographic regions, including state to state.

Based on the NAIC Climate Risk Disclosure Report, reported engagement in climate-related activities has increased since the survey has been collected starting in 2010. The insurance industry faces potentially

[38] Hirtzer, Nicholson, and Chipman, 2021.
[39] Crane-Droesch, Marshall, Rosch, Riddle, Cooper, and Wallander, 2019.
[40] Pryor, Scavia, Downer, Gaden, Iversion, Nordstrom, Patz, and Robertson, 2014.

significant impacts from the escalating effects of climate change due to its exposure to weather-related risks.

Based on our case study of the Midwest region, the variables we analyzed (drought indices and Billion-Dollar Event Costs) have predictive power with respect to estimating crop prices. Our model forecasting shows that prices are projected to increase well into the future, which will affect the availability and affordability of crop insurance if the FCIP becomes too cost prohibitive to insureds without additional government intervention.

Adaptation methods such as shifting locations and methods of production have the potential to mitigate the risk of lower and volatile crop yields over time[41]. Expected crop yields are projected to improve with better irrigation and lower greenhouse gas concentration scenarios. Additionally, new innovations are being undertaken such as BlockChain, FarmersEdge, and Index Insurance.

4.2 AREAS FOR FUTURE RESEARCH

Areas for future research include the following:

- Expanding the model/forecast to include additional variables, interactions, time periods, etc., to determine the most accurate model in predicting future affordability and availability.
- Expanding the model beyond the Midwest to include additional geographies, to include on regional and worldwide impacts and determine which areas will be more or less impacted by affordability and availability issues.
- Performing a retrospective actual versus expected analysis of the model to determine accuracy by year and variability.
- Alternative approaches to projecting future crop prices, to determine if historical assumptions are satisfactory or if new, forward-looking assumptions are necessary to predict the ever-changing climate.
- Researching the impact from the insured’s perspective, including interviews to determine the largest issues facing insureds and glean further insight into their biggest needs that should be addressed in the future.
- Researching differing impacts by different emissions scenarios, to account for more future scenarios to help make even more informed decisions surrounding the future of affordability and availability.
- Researching future political/government support of the FCIP, including issues associated with the congressional subsidy budget and a comparison of other nation governmental actions taken in response to climate change.
- Researching further the secondary implications on availability of adequate food sources in areas dependent on crops.

[41] Crane-Droesch, Marshall, Rosch, Riddle, Cooper, and Wallander, 2019.

Section 5: Acknowledgments

The researchers' deepest gratitude goes to those without whose efforts this project could not have come to fruition: the Project Oversight Group and others for their diligent work overseeing questionnaire development, analyzing and discussing respondent answers, and reviewing and editing this report for accuracy and relevance.

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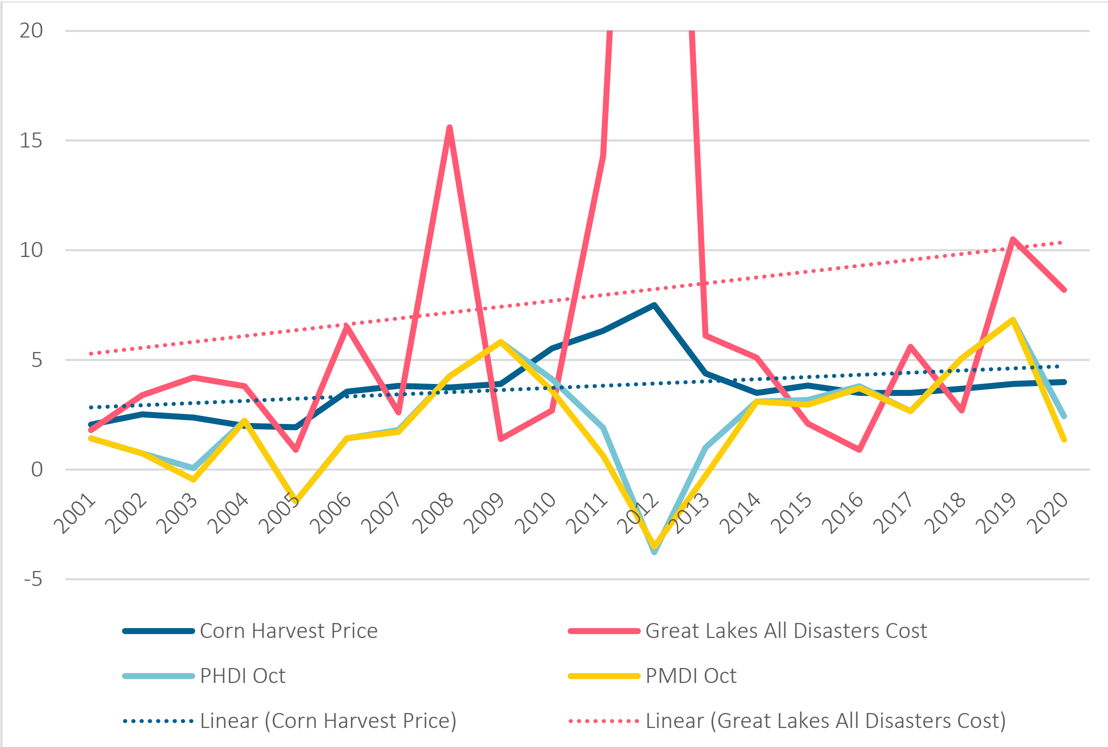
Appendix A: Modeling Graphs/Background

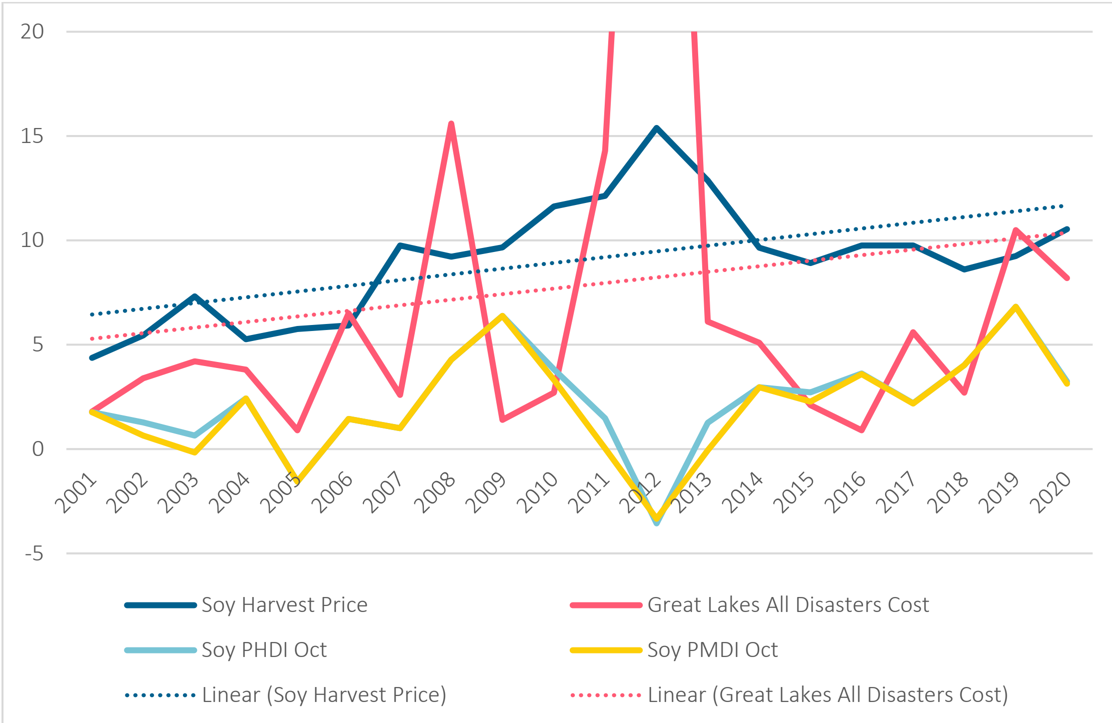
Figure 6
CORN PREDICTIVE VARIABLES



Data Source: NOAA and USDA.

Figure 7

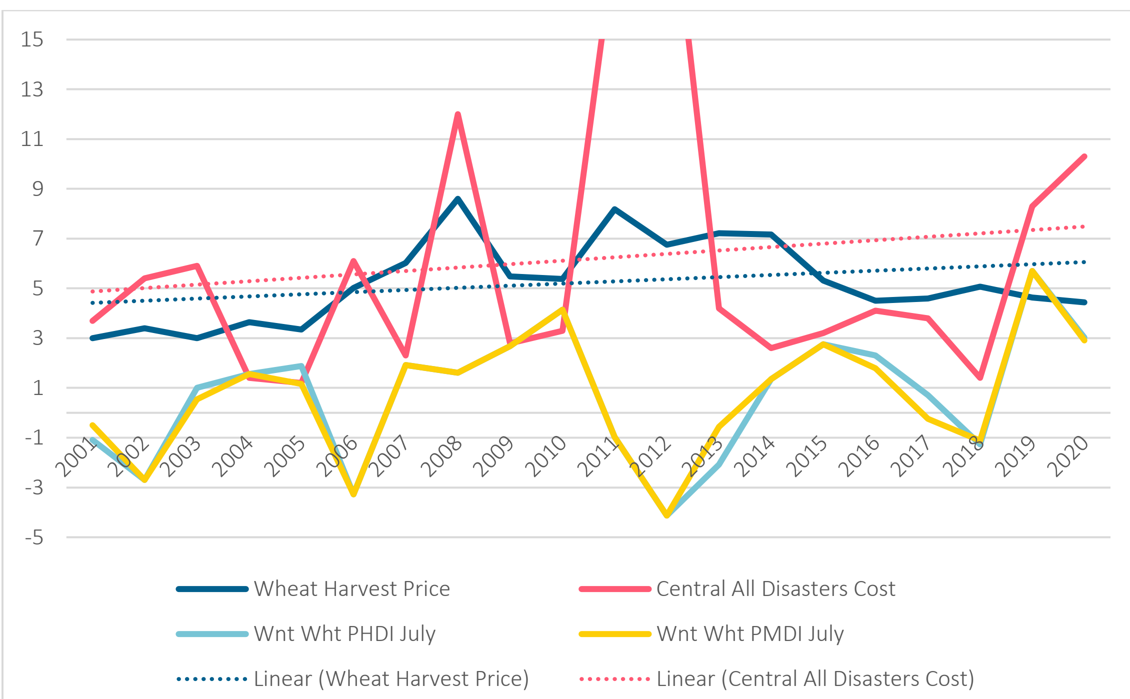
SOYBEAN PREDICTIVE VARIABLES



Data Source: NOAA and USDA.

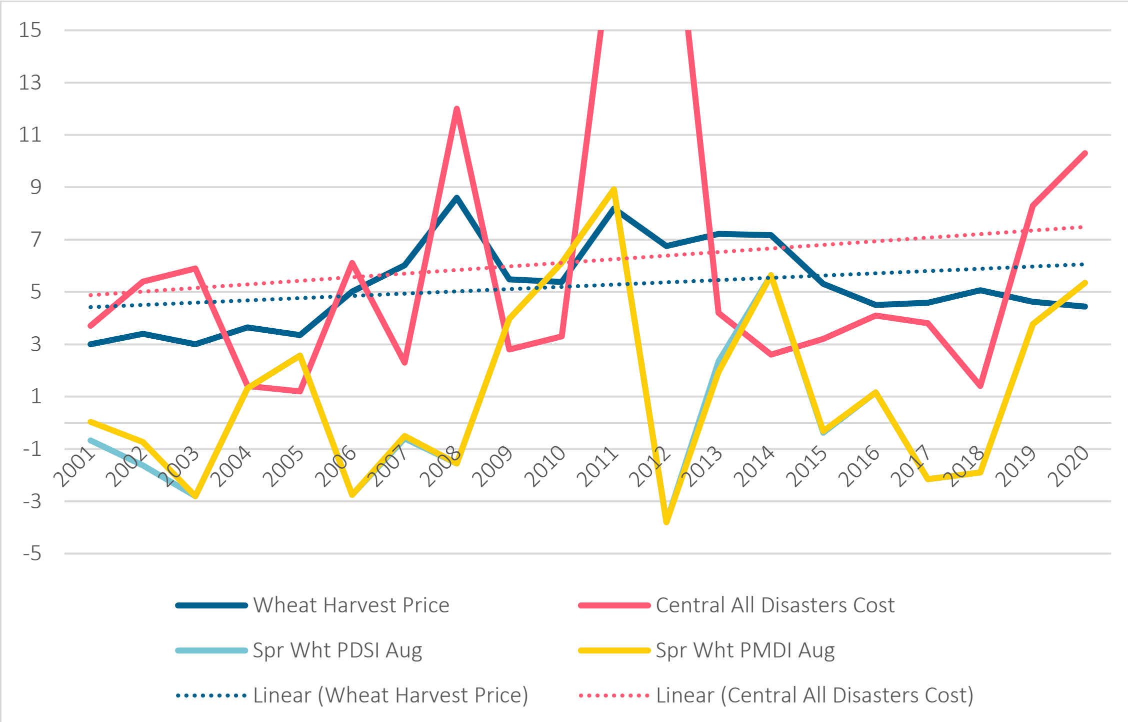
Figure 8

WINTER WHEAT PREDICTIVE VARIABLES



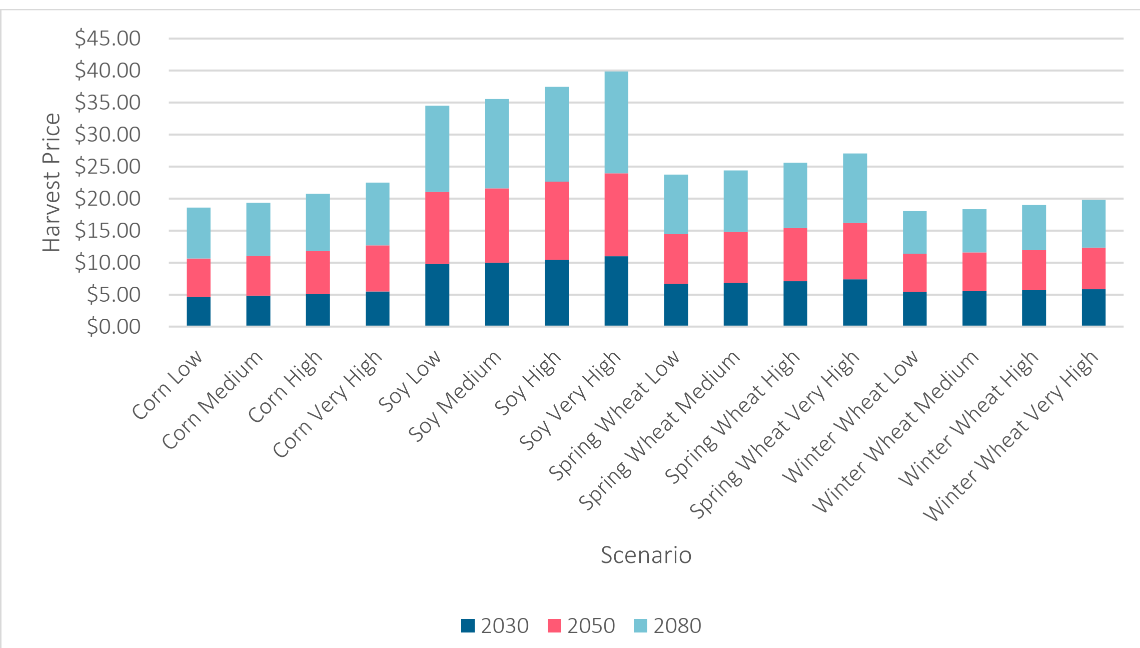
Data Source: NOAA and USDA.

Figure 9
SPRING WHEAT PREDICTIVE VARIABLES



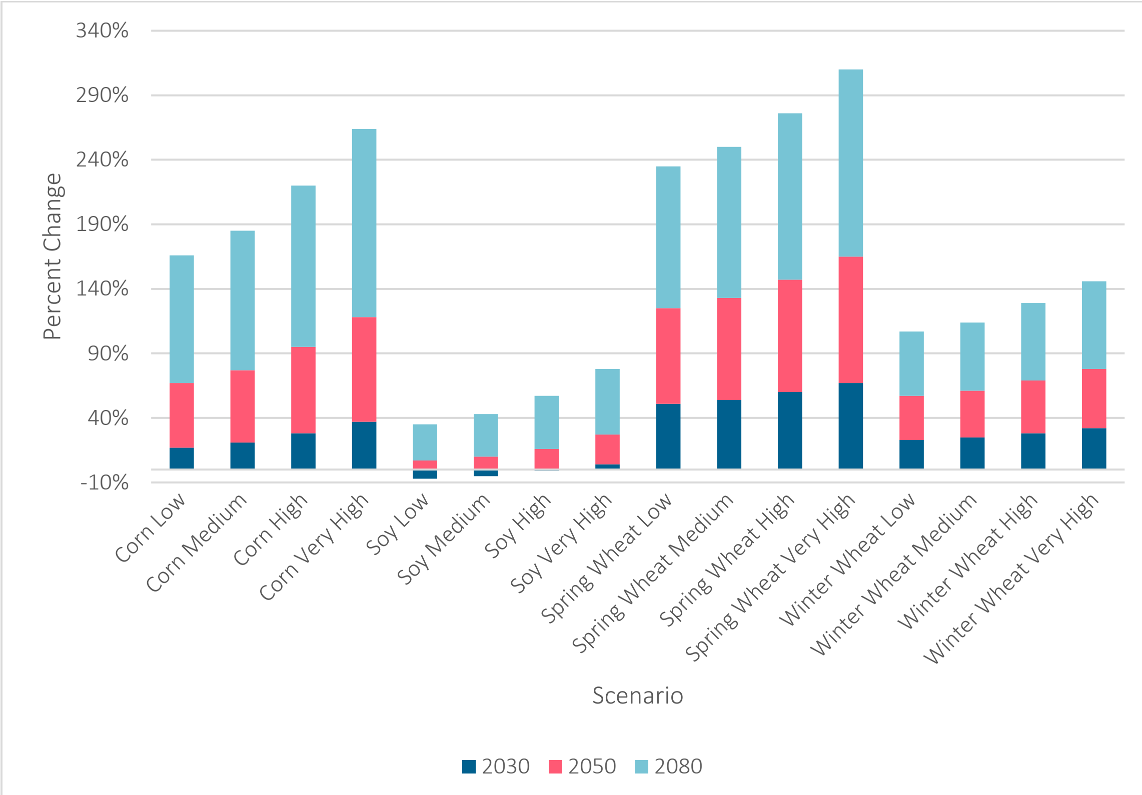
Data Source: NOAA and USDA.

Figure 10
FUTURE PROJECTED HARVEST PRICE



Data Source: NOAA and USDA.

Figure 11
FUTURE PERCENT CHANGE IN HARVEST PRICE



Data Source: NOAA and USDA.

To give some additional background, we selected linear trending into the future because it represented the line of best fit and using other trend types such as exponential would lead to alarmist scenario outcomes, which we were trying to avoid. Strengths of the model are its simplicity and ease of understanding as well as its intuitive nature as it is not overly technical or complex. Weaknesses are it may not be the best fitting model, nor does it consider other variables, variable interactions, scenarios, or possibilities that could potentially provide additional signal. We believe that the changing emissions amounts will lead to more drastic weather extremes (drought, precipitation, etc.), which will then lead to lower crop yields, higher crop insurance prices, and thus lower affordability and availability of crop insurance due to the increasing cost of crop insurance and the FCIP without additional government subsidy.

See below for information regarding the climate models, emissions under the 4 scenarios, and adaptation. Please not that items in italics are drawn from the research article "Climate Change and Agricultural Risk Management Into the 21st Century". We quantify the impact of adaptation by relying on different relativities drawn from the article.

Different Climate Models Used

> *Future climate scenarios used in our analysis were taken from five climate models: the Hadley Centre Global Environment Model (HadGEM), the Community Climate System Model (CCSM), the Canadian Earth System Model (CanESM), the Model for Interdisciplinary Research on Climate (MIROC), and the Goddard Institute for Space Studies model (GISS). These models were all run*

under the auspices of the Coupled Model Intercomparison Project (Taylor et al., 2012) and differ in their methods for numerically representing the physics of the atmosphere.

Like many climate change impacts studies, we use multiple models to capture the uncertainty about the evolution of the climate system in response to emissions of greenhouse gasses. Each model is driven by the same emissions scenarios, but the resultant climates that they simulate differ to a substantial degree. While they all share certain characteristics—notably, increase in average temperature with increasing concentrations of greenhouse gasses—they differ in the spatial patterns of temperature change, precipitation change, and degree of average warming.

Emissions Scenarios

The emissions scenarios—termed "representative concentration pathways" (RCP) (Van Vuuren et al., 2011)—represent possible future emissions pathways to the year 2100. We use RCP4.5 and RCP8.5, which represent stabilization of greenhouse gas concentrations at double pre-industrial levels and continuation of recent rates of increase in greenhouse gas concentrations, respectively. RCP4.5 can be interpreted as a simulated climate future in which some amount of climate change mitigation occurs, and RCP8.5 can be interpreted as one in which no mitigation occurs.

Farmer Adaptation

We model farmer adaptation to changing climate using REAP, which is a partial equilibrium model of the U.S. agricultural sector. REAP estimates producers' response to shocks, and market response to those producer decisions (see box "The REAP Model").

The REAP model is initialized with a baseline scenario developed for Marshall et al. (2015). In that study, reference conditions were developed based on expert advice, literature, and a modified extrapolation of the USDA 10-year baseline forecast and reflect a continuation of historic trends (population, diet, demographics, and other socioeconomic factors), but without climate change. As the climate scenarios alter yields over space, the REAP model simulates how acreage would shift from this baseline.

Projection of future yields based on past relationships between weather and yields implicitly assumes that the relationship between weather and yield will remain constant over time. If greater severity of climate change leads to decreasing sensitivity of yield to climate, then the assumption of constant sensitivity would lead to a downward bias in yield projections into the future. Despite the theoretical plausibility of this potential source of bias, recent empirical studies don't yet support it (Burke and Emerick, 2016; Lobell et al., 2014). Furthermore, we emphasize that our main purpose in scenario-building is the exploration of the factors mediating their differences, in order to understand the mechanisms by which climate change could affect Federal agricultural risk management programs.

Adaptation in the form of shifting locations and methods of production has the potential to mitigate overall production declines, as well as change levels of interannual production volatility. We explore the importance of adaptation by running REAP twice—once in which acreage is held fixed to baseline values (which are projections out to 2080 based on the dynamics underlying the USDA baseline (Marshall et al., 2015)) and once in which acreage is allowed to shift in response to new expected yields. These are termed "no adaptation" and "adaptive acreage." Their implications for total production are shown for each climate model in our analysis in figure 5. There is substantial heterogeneity in the magnitudes of yield projections by climate model for corn and soybeans, whose impacts are largely parallel, and some heterogeneity in winter wheat, where *impacts are small. In corn, total production is very similar between the adaptive acreage and no-adaptation scenarios, though average declines tend to be slightly larger under the adaptive acreage scenario. In soybeans, losses are larger in the no-adaptation scenario, and decreasing in proportion to the degree that no-adaptation production declines from baseline.*

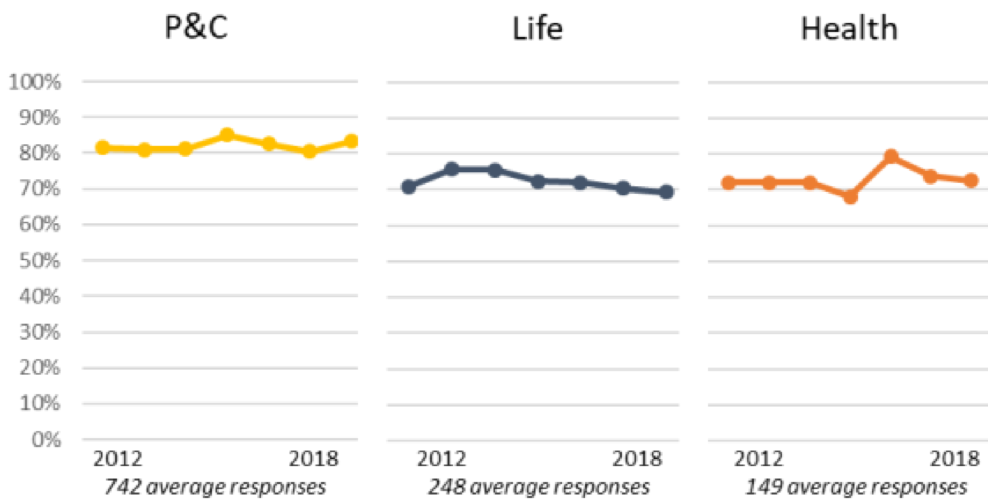
The dynamics observed under the "adaptive acreage" scenario are driven by yield change (mapped in fig. 3) as well as the movement of planted acreage in response to expected yield change (mapped in fig. 6). The REAP model alters acreage in response to changes in expected yields and prices under climate change, which leads to substantial shifts in where production is located, how much acreage is planted, and how crops are grown. The model projects that national acreage in corn, soybeans, and wheat will decline under both emissions scenarios, though there is substantial variability across regions (table 1 and figure 7).

The REAP Model Additional Details

The Regional Environment and Agriculture Programming (REAP) model is a static, partial equilibrium optimization model of the agricultural sector that quantifies agricultural production and its associated environmental outcomes for 273 regions in the United States. REAP employs detailed input (derived from the USDA Agricultural Resource Management Survey (ARMS), the National Resources Inventory (NRI), and the Environmental Policy and Integrated Climate (EPIC) model) at the regional level on crop rotations, crop yields, input requirements, costs and returns, and environmental parameters to estimate longrun equilibrium outcomes. Regional production levels are determined for 10 crops, including the 3 crops analyzed here, and 13 livestock categories, and national production levels are determined for 20 processed products. For each REAP region, land use, crop mix, multiyear crop rotations, and tillage practices are all endogenously determined by REAP's constrained optimization process, which implicitly assumes that farmers are risk-neutral actors. Cropland allocations, aggregate input use, and national prices are determined endogenously.

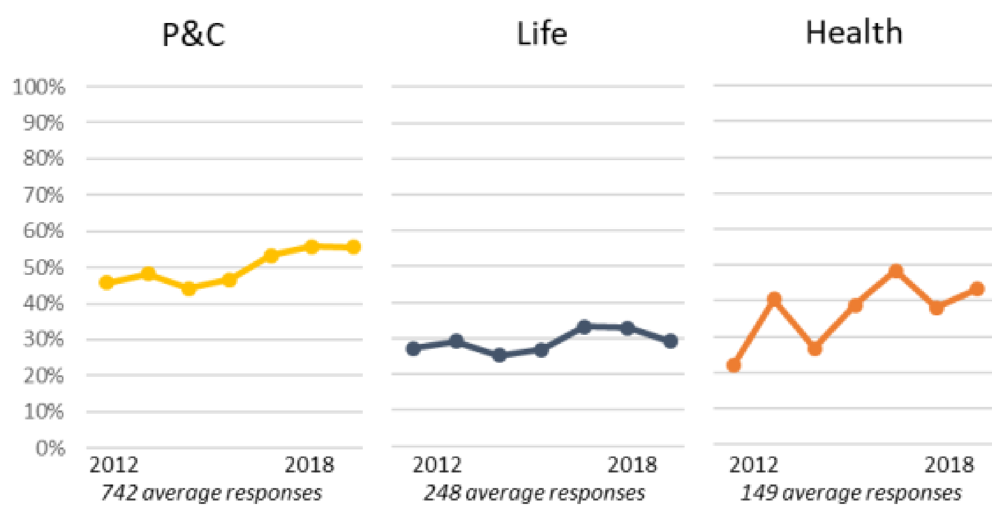
Appendix B: NAIC Climate Risk Disclosure Data Survey Results[42]

1. **EMISSIONS** Does the company have a plan to assess, reduce or mitigate its emissions in its operations or organizations? If yes, please summarize.



Source: National Association of Insurance Commissioners

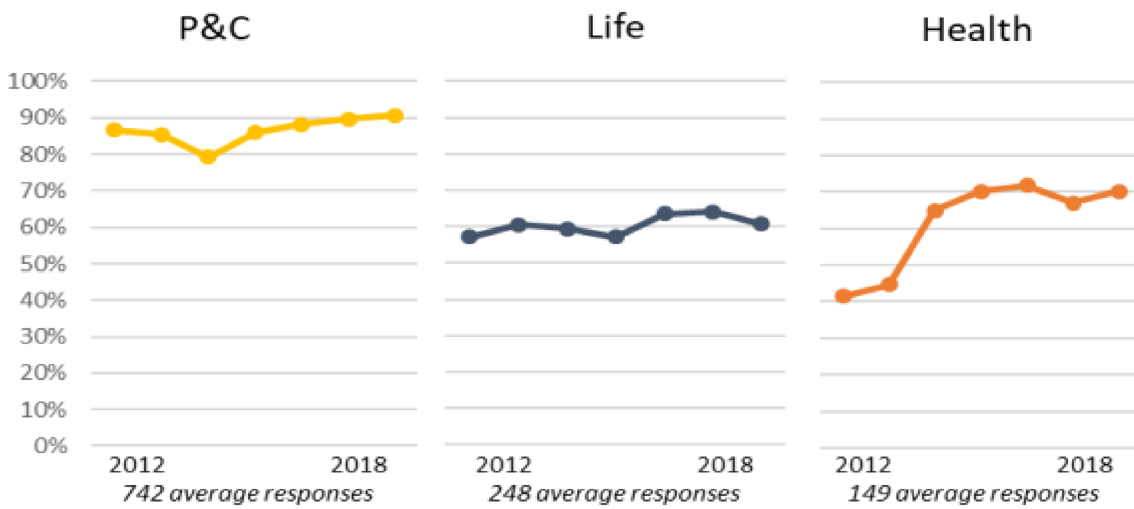
2. **RISK PLAN** Does the company have a climate change policy with respect to risk management and investment management? If yes, please summarize. If no, how do you account for climate change in your risk management?



Source: National Association of Insurance Commissioners

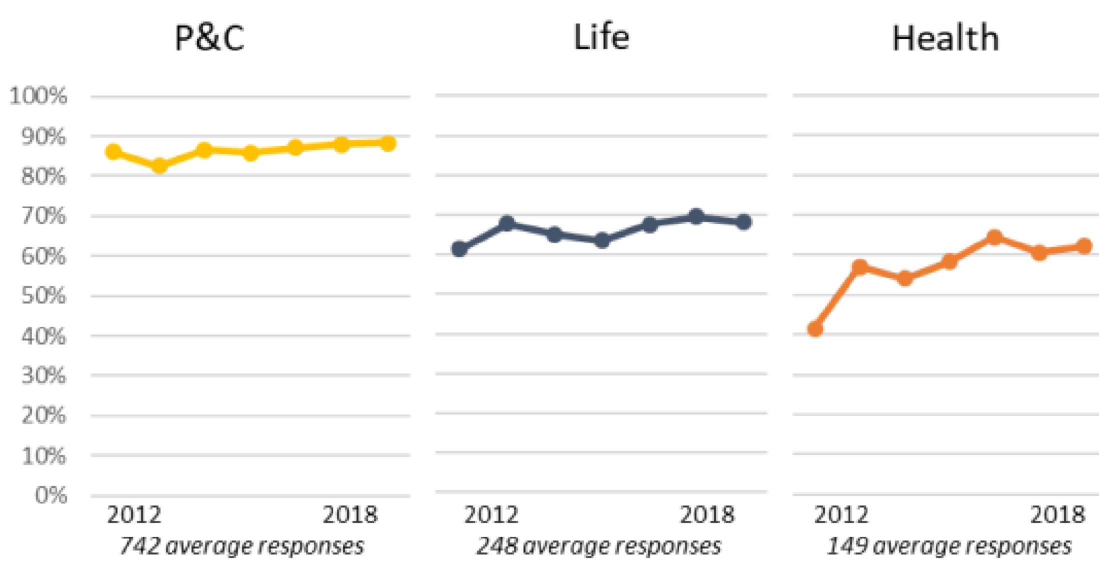
[42] Groshong, Czajkowski, Harms, Zhang, and Dahman, 2020, pages 24-29. [reprinted with permission]

3. ASSESS Describe your company's process for identifying climate change related risks and assessing the degree that they could affect your business, including financial implications.



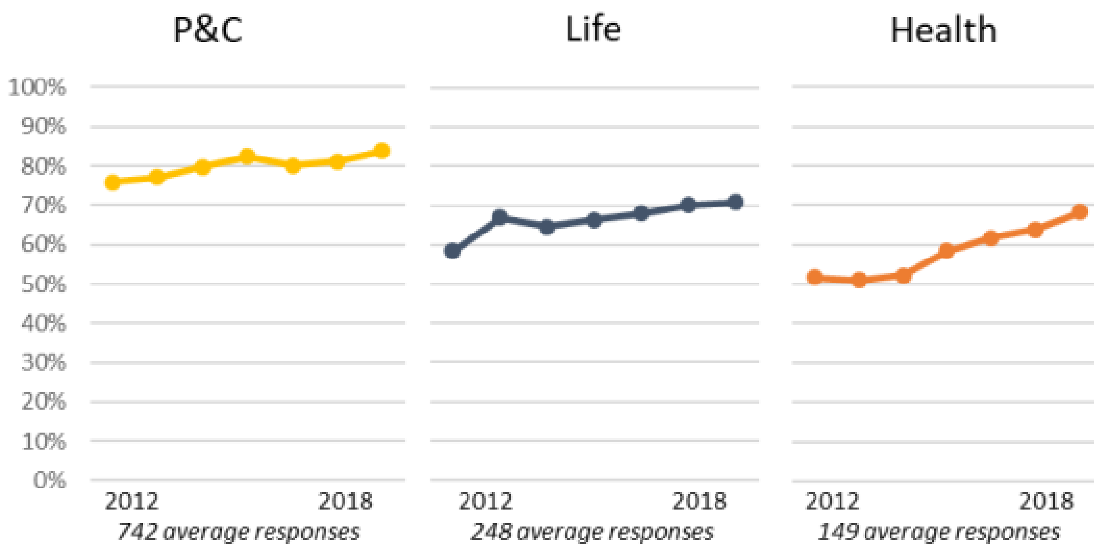
Source: National Association of Insurance Commissioners

4. RISKS Summarize the current or anticipated risks that climate change poses to your company. Explain the ways that these risks could affect your business. Include identification of the geographical areas affected by these risks.



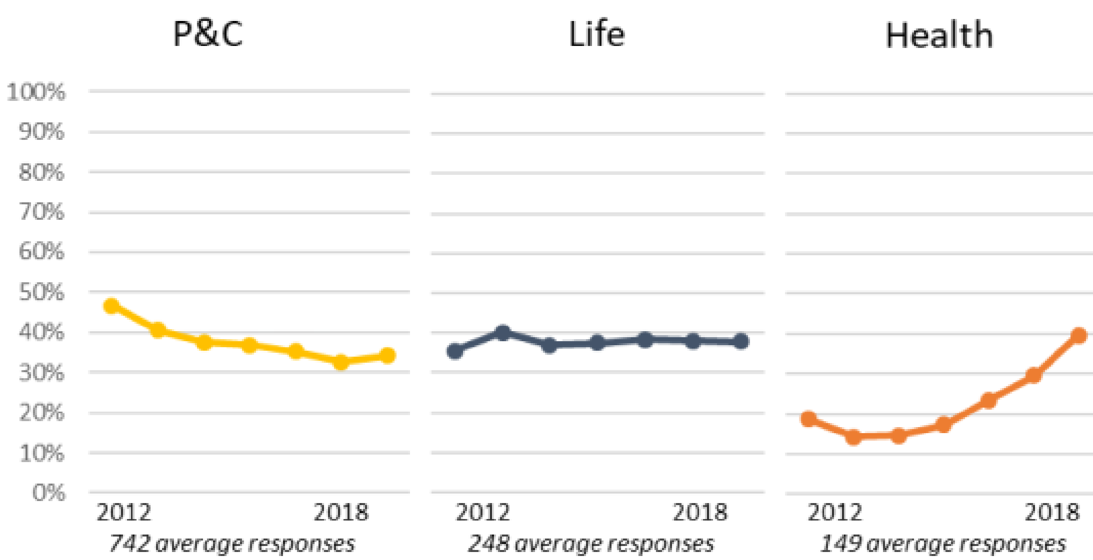
Source: National Association of Insurance Commissioners

5. **INVEST** Part A: Has the company considered the impact of climate change on its investment portfolio?



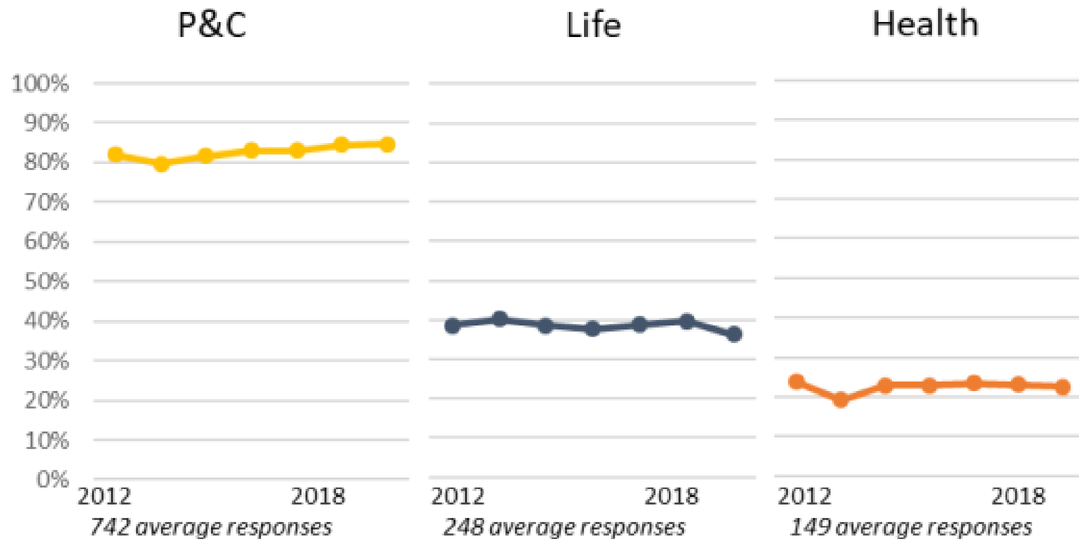
Source: National Association of Insurance Commissioners

Part B: Has it altered its investment strategy in response to these considerations? If so, please summarize steps you have taken.



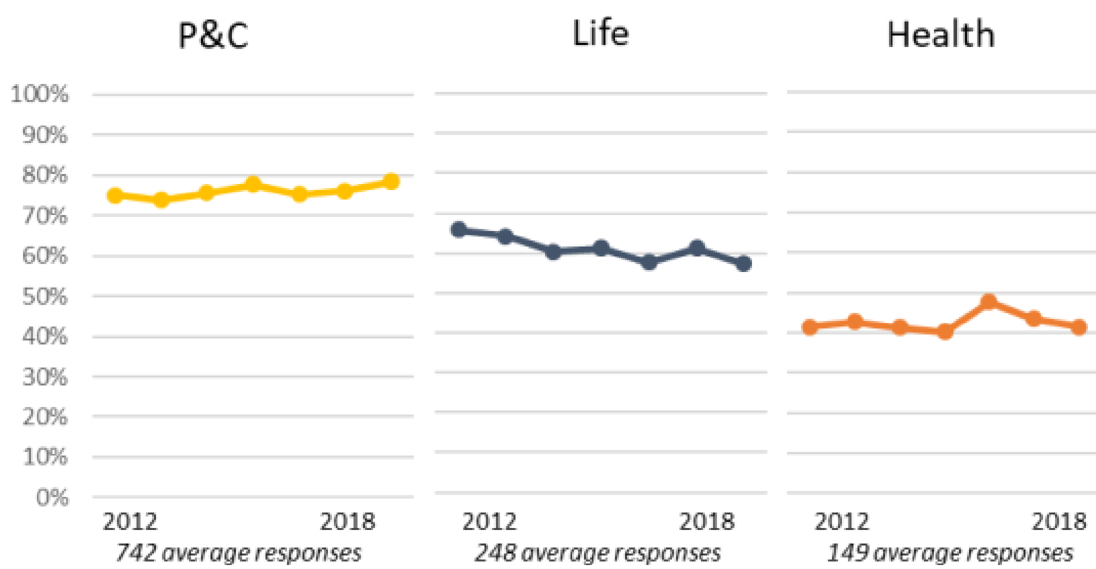
Source: National Association of Insurance Commissioners

6. **MITIGATE** Summarize steps the company has taken to encourage policyholders to reduce the losses caused by climate change-influenced events.



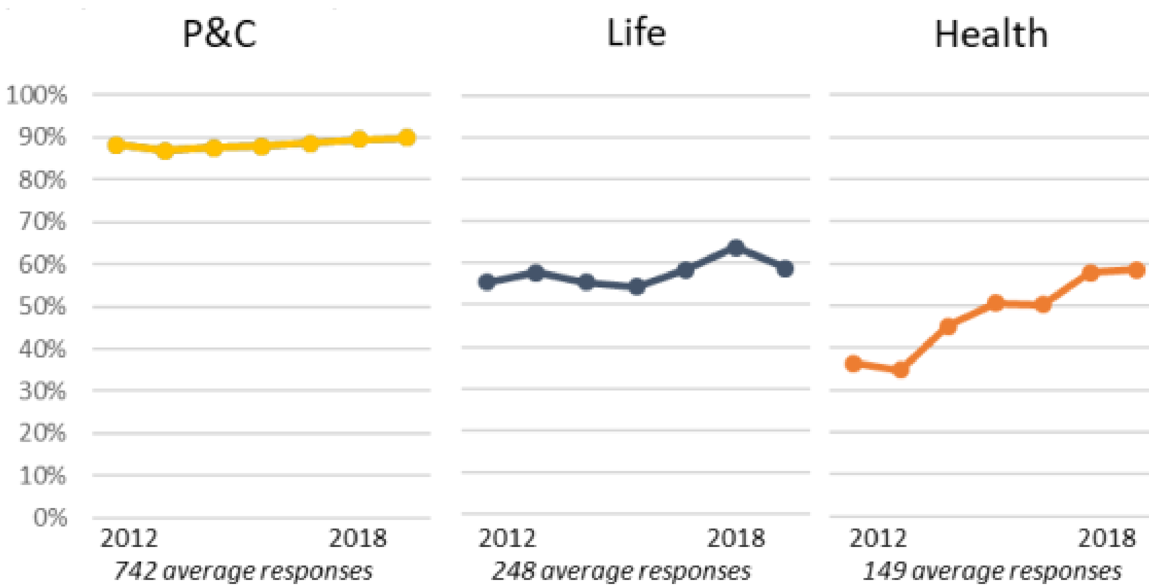
Source: National Association of Insurance Commissioners

7. **ENGAGE** Discuss steps, if any, the company has taken to engage key constituencies on the topic of climate change.



Source: National Association of Insurance Commissioners

8. MANAGE Describe actions the company is taking to manage the risks climate change poses to your business including, in general terms, the use of computer modeling. *If Yes* – Please summarize what actions the company is taking and in general terms the use if any of computer modeling in response text box.



Source: National Association of Insurance Commissioners

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Serving as the research arm of the Society of Actuaries (SOA), the SOA Research Institute provides objective, data-driven research bringing together tried and true practices and future-focused approaches to address societal challenges and your business needs. The Institute provides trusted knowledge, extensive experience and new technologies to help effectively identify, predict and manage risks.

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