Potential for Farm Adaptation to Global Climatic Change in Kentucky

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Summary

Discrete Sequential Stochastic Programming techniques are employed to investigate the potential for farm adaptation to global climate change in Kentucky. Multiple sources of production risk expected under climate change and potential adaptation avenues are modeled providing a comprehensive farm level impact assessment. Results from the study provide insights on the nature of production shocks due to climate change, optimal avenues of adaptation by producer risk preference under climatic change.

Introduction

The intergovernmental panel on Climate Change projects the mean temperature increases in the order of 1 C to 3.5 C by the year 2100, simulating both spatial and temporal changes in global weather patterns. The impact of these changes on human and natural ecosystems has been extensively studied (e.g. Riebsame). The impact of climatic change on agriculture has been of special interest to researchers, considering the importance of the sector to human sustenance and livelihood (See: Easterly *et al.*, Onal and Fang, Kaiser *et al.*, Mount and Li, Rozenweig, Hansen *et al.*). However, many of the past works did not present a complete picture of the potential future risks nor adaptation avenues available to the producer. For example, works by Rozenzweig provide consistently bleaker pictures in climactic scenarios when not considering farm adaptation. While the later works by Kaiser *et al.*, and Mount and Li provide a wide range of adaptation avenues, they fail to adequately represent all sources of production risk. Many of the past works are also plagued by lack of climate model estimated future inter-annual variability estimates. Kaiser *et al.* make use of a statistical weather generator to arrive at variability imposed future climate scenarios to overcome this data constraint. Dixon and Segerson resort to a variant of the Ricardian methodology to study the impact of climate variability in Midwest agriculture. There is also a need to study adaptation to climatic change using an appropriate decision structure. Many previous studies relied on simplistic designs that fail to adequately represent the production environment. Kaiser *et al.*, make use of a Discrete Sequential Stochastic Programming (DSSP) approach to represent the sequential nature of farm decision process and the realistic nature of production risk. They also forecast future crop prices by constructing price reduced form equations from historic price series.

The present paper presents a mathematical programming model that represents for future production risks and allows for multiple avenues that enable producers to adapt to adverse shocks from climatic change. The specific objective of the effort is to investigate the economic, farm management as well as marketing responses of producers to climatic change. By doing so, the potential for farm adaptation to climatic change across levels of producer risk preference can be understood.

Specifically, the study while adopting the DSSP approach, adds new complexities into the issue. First, it employs climate model generated values of future climate variability, providing for realistic weather scenarios. Second, a closer representation of the complete set of production risk is portrayed through inclusion of yield, suitable field day risk as well as price risk. Thirdly, a range of producer adaptation strategies including alternative production strategies, custom hiring as well as storage options are incorporated. Fourth, crop output prices are generated as a mean reverting jump diffusion process to represent the stochastic nature of prices. Fifth, the study considers a greater range of producer risk aversion than previous efforts allowing for greater analysis on the impact of risk aversion on optimal decision under climatic change. The study is conducted for a representative row crop producer operating in Henderson County, Kentucky across different levels of risk preferences.

Research Method

Discrete stochastic programming techniques are linked to biophysical simulation techniques to select optimal cropping portfolios across producer levels of risk preference. In brief, the research procedure involved simulating crop production data across future and current weather scenarios using biophysical simulation models. This data along with economic parameter specifications is used in an economic decision making model to generate optimal cropping portfolios for each levels of producer risk preference. In the following sections the detailed procedure is discussed under the following headings: a). Weather Scenarios, b). Biophysical Model and c). Economic Component.

a). Weather Scenarios

The starting point for predicting future climactic change impacts is through definition of appropriate scenarios that depict plausible pictures of the future. For the present study two weather scenarios are generated. The Base scenario represents the 22 years of historical weather data for Henderson County from 1978-2002 obtained from the agricultural weather station, University of Kentucky, Lexington. The Base is modified using estimates from General Circulation Models (GCM) to arrive at the Mean-Var scenario, which represents future weather. GCM forecast changes in regional temperature, precipitation, evapotranspiration and other climate variable associated with changes in green house gas concentration. These models represent the earth's climate system at a discrete series of points, usually with a resolution of a few hundred kilometers in the horizontal plane and few kilometers in the vertical. The preferred source for future climate data is through the use of one or more of atmospheric-ocean coupled

GCMs. Frequently used candidates include: Goddard Institute of Space Studies (GISS), Hadley-UKMO model, and Geophysical Fluid Dynamics Laboratory (GFDL) to name a few. The present study uses estimates from the GISS GCM alone, owing to the availability of future variability estimates in weather parameters and the focus of the study on farm adaptation. The inclusion of weather variability is considered important because of the significant effect it has on agricultural resources and farm management decisions (Mearns *et al.*). Further, the IPCC recognizes the importance of variability in impact assessments studies by noting “a small change in variability has a stronger effect (on the frequency of extremes) than a small change in the mean” (Houghton *et al.*,)

The Mean-Var scenario was constructed by a simple linear transformation of the historic weather data using mean and standard deviation estimates for monthly temperature and precipitation changes under future climatic change for the southeastern United States. The use of observed historic time series data provides an accurate baseline climate, from which a portrayal of GCM predicted future climate could be drawn. Furthermore, the straightforward technique employed here provides a practical way of generating daily weather data, demanded by crop response models, from monthly averaged information typically available from GCMs. In constructing the weather scenarios, the total number of rain events was held constant as the base case. When the transformation yielded illogical negative rain, no rain event was assumed. More information on the GISS GCM and the estimates used in the study can be had from Hansen *et al.*

b.) Biophysical Model

The Biophysical scenario represents the crop combinations and production alternatives along with resources available to the farm firm. This component generates crop yields and suitable field day resources by weather scenarios for use in the economic decision making model. Four crop enterprises of corn, single crop soybean, wheat and double cropped soybean with wheat. Biophysical modeling techniques are employed to generate 22 years of crop yield data for the specified crops and across three different states of likelihood of a day being suitable for field work. The crop simulation involved the use of CERES-SOYGRO (Ritchie and Otter, Wilkerson *et al.*) family of crop simulators for generating single crop soybean, wheat and double cropped soybean yields and the CORNF (Stapper and Arkin) corn simulator was used to generate corn yields. The crop simulation was performed assuming a no till rainfed cultivation as is representative of the study region. One of the reasons for selecting the above set of crop simulators was their ability to simulate crop response surface across a range of alternative production practices. The inclusion of alternative production practices enables the producer to realistically adapt to climatic change beyond conventional considerations of yield risk alone.

The alternative production practices included in the present framework involve alternative planting dates, plant populations and maturity classes for the specified crop enterprises. Data from the Kentucky Agricultural Statistics (2002) and Extension Specialists was used to design the alternative production decisions. Corn planting was carried out over nine weekly intervals from March 29th to May 24th involving low, medium and high plant populations. Corn production also allowed early, medium and late maturity group choices. Single crop soybean was planted in nine weekly planting dates from April 26th until June 21st and involved MG 3, MG 4 and MG 5 maturity groups. Soybean plant population involved six plant and row spacing combinations: row spacing of 9 inches (with two and three plants per foot), 19 inch rows (with four and six plants per foot) and 30 inch rows (with six and nine plants per foot). Double cropped soybean plant population and maturity group choices paralleled those of single crop soybean. Double cropped soybean planting dates were carried out 5 days after the harvest of wheat. Wheat planting dates ranges from September 27 to November 22 and did not include any plant population or maturity group choices.

The weekly days suitable for fieldwork are simulated using a soil water simulation developed using a modified procedure discussed by Dillon, Mjelde and McCarl. Specifically, the biophysical simulator was designed modifying the CORNF crop response model for the purposes of generating suitable field days. The simulation process uses daily weather data to account for soil moisture in the field and eliminates certain days as not suitable for fieldwork based on pre-specified rules. Days suitable for fieldwork are calculated across three different states of likelihoods for the weather data specified under the Base and Mean-Var scenarios. This data is then transformed into an appropriate labor constraint by multiplying the average number of suitable field days in week by 12 working hours a day for 2.56 persons. This represents the representative labor scenario in an Ohio valley region grain farm (Morgan). Thus labor availability across 3 different states for the two scenarios is obtained for purposes of study.

c. Economic Component

The underlying economic decision making framework is constructed in a DSSP framework, representing the profit and risk considerations of the producer. The approach offers a realistic way of modeling the underlying production risk environment and the sequential nature of producer decisions. The framework allows one to model uncertainties in the right hand side, technical coefficients as well as in the objective function as a multi-stage decisional process. The model structure is characterized by a sequence of decision dates or stages along with a set of decision variables for each stage. The source of uncertainty is represented by a number of discrete random states of nature for each stage. It is important to logically represent the flow of information among the various stages in the decision process, in other words, to construct a decision tree for the problem at hand (Kaiser and Apland).

The present study comprises of a two-stage DSSP model. These include stage 1, crop production stage and stage 2, crop marketing stage. The producer enters the crop production stage making a series of decisions involving land allotment (crop enterprises), crop production (choice of alternative production practices) and management (custom hiring/own resources) decisions while facing three different equally likely states of suitable field day uncertainty. Recall that the uncertainty on the suitable field days directly affects the labor availability for the farm. Change in annual precipitation patterns under climatic change may potentially result in large rainfall during short intervals of time. The implication under the present model structure is a decrease in number of suitable field days and consecutively the labor employable. The suitable field day risk therefore is an important component in representing the new production risk environment confronting the producer under global climatic change. The adaptation avenue for managing this risk is through custom hiring of crop operations. The idea under the design is that producers can relax the labor constraint by outsourcing crop operation requirements when facing labor resource problems due to lack of suitable field days.

In stage 2, the producer has complete knowledge of previous states of nature but only a probabilistic knowledge of the current states. The producer in this stage makes the decision to sell or store crop produce while facing 75 equally likely states of crop prices each week. Considering the stochastic design of the study, it was important to appropriately model crop prices to depict uncertainty in crop prices for both scenarios envisaged for the study. The study makes use of a mean reverting jump diffusion process to simulate crop prices for 75 different states for use in the economic model. These states are comprised of three possible realizations over a 25 year period providing a range of equally likely price outcomes. This approach is considered innovative considering it has not been previously applied in farm level assessment of climatic change impacts. The adaptation avenue to manage risk due to price is by allowing the producer to store crop produce. As mentioned earlier yield risk in the model can be managed through a series of alternative production practice choices. The complete model allows for 5,625 number of joint revenue events and was solved using MINOS 5.0. A detailed explanation of the model structure describing the variables and constraint follows.

Objective Function: Max $Y - \phi\, \sigma^2_y$

Subject to the following constraints

1). $\Sigma_E\, \Sigma_V\, \Sigma_P\, \Sigma_S\, X_{E,V,P,S} \leq 1350$

2). $\Sigma_E\, \Sigma_O\, \Sigma_{MO}$ LAB $_{E,O}$ PURCH $_{E,O,MO,WK,PER} \leq$ LABOR $_{WK,PER}$ $\quad \forall$ WK, PER and MO= OW

3). $\Sigma_V\, \Sigma_P\, \Sigma_S \Sigma_O$ EXPYLD$_{E,V,P,S,YR}$ $X_{E,V,P,S}$ OPER$_{E,V,S,O,WK}$ – PRODUCE $_{E,N,WK,PER} = 0$ $\quad \forall$ E, WK, PER, N and O= HAU$_E$

4). $\Sigma_E\, \Sigma_V\, \Sigma_P\, \Sigma_S$ OPER$_{E,S,V,WK,O}$ $X_{E,V,P,S}$ - $\Sigma_E\, \Sigma_{MO}$ PURCH $_{E,O,MO,WK,PER} \leq 0$ $\quad \forall$ O, WK, PER

5). $2^*\Sigma_E\, \Sigma_V\, \Sigma_P\, \Sigma_S\, X'_{E,V,P,S} - \Sigma_E\, \Sigma_V\, \Sigma_P\, \Sigma_S\, X''_{E,V,P,S} = 0$ $\quad$ Where X' = CORN and X'' = Soybean

6). CSELL $_{E,N,WK,PER}$ + CSTORE $_{E,N,WK,PER}$ = PRODUCE $_{E,N,WK,PER}$

7). CSELL $_{E,N,WK,PER}$ + CSTORE $_{E,N,WK,PER}$ - CSTORE $_{E,N,WK-1,PER}$ = PRODUCE $_{E,N,WK,PER}$

6). $\Sigma_E\, \Sigma_O\, \Sigma_{MO}\, \Sigma_{WK}$ IP $_{E,O,MO}$ PURCH $_{E,O,MO,WK,PER}$ $-\Sigma_E\, \Sigma_{WK}$ STORCOST$_{E,WK,R}$* CSTORE$_{E,N,WK,PER}$ - $\Sigma_E\, \Sigma_{WK}$ CSELL$_{E,N,WK,PER}$ CRPRICE$_{E,WK,R}$ + Y $_{N,R,,PER,S} = 0$ $\quad \forall$ N, PER, R

7). $\Sigma_N \Sigma_{PER} \Sigma_R$ (1/(N*N1*PER*R))* (a $_N$ * ? $_{PER}$*μ_R* Y $_{N,PER,R}$) - Y = 0

8). CSTORE$_{E,N,WK,PER}$ + Σ_E CSELL$_{E,N,WK,PER}$ =0 $\quad \forall$ WK = 52

Where activities include:

1. Y = Mean profits
2. Y $_{N,PER,R}$ = Profits by PER suitable field day and R price states for N yields
3. X $_{E,V,P,S}$ = Production of enterprise E of variety V with population P under sowing date S in acres.
4. PRODUCE $_{E,N,WK,PER}$ = bushels of enterprise E across N yields by Wk week and PER suitable field day states.
5. PURCH $_{E,O,MO,WK,PER}$ = Purchases of operation O for enterprise E by management option MO in week WK

6. $CSELL_{E,N,WK,PER}$ = bushels sold of crop enterprise E across N yields in week WK in PER suitable field day states
7. $CSTORE_{E,N,WK,PER}$ = bushels stored of crop enterprise E across N yields in week WK in PER suitable field day states

Constraints include:

1. Land resource constraint
2. Labor resource limitations by week when own resources are employed
3. Produce balances by crop and year
4. Operations balances
5. Crop rotation constraint
6. Initial balance between selling and storage decisions
7. Ending balances
8. Marketing flow balance between storage and selling across weeks WK
9. Profit balances by year
10. Expected profit balance

Coefficients include:

1. ϕ = Pratt risk aversion coefficient
2. $CRPRICE_{E,WK,R}$ = Price of crop enterprise E in dollars per bushel and R price states by week WK
3. N = Number of yield years
4. $IP_{E,O,MO}$ = Cost of operation O for enterprise E employing management option MO
5. $EXPYLD_{C,E,V,P,S,N}$ = Expected yield of crop C for enterprise E of variety V planted in population P on sowing date S in bushels per acre by year N.
6. $OPER_{E,S,V,WK,O}$ = Field operation requirement O for enterprise E in sowing date S and variety V in week WK
7. $STORCOST_{E, WK, R}$ = Storage costs per bushel for enterprise E across R price states by week WK.
8. $LAB_{E,O,MO}$ = Labor requirements for production of enterprise E and for operation O under management option MO.
9. $FLDDAY_{WK,PER}$ = Available field days per week at varying levels of certainty across PER states of suitable field days
10. a_N = Probability associated with yield state
11. $?_{PER}$ = Probability associated with suitable field day state
12. μ_R = Probability associated with price state

Indices include:

1. C = Crop
2. E = Enterprise
3. V = Variety (MG 3, MG 4, and MG 5 for soybeans or early, medium, and late for corn)
4. P = Plant Population
5. S = Sowing Date
6. WK = Week

7. MO = Management Option (HR = custom hire, OWN = Own)

The objective function maximizes the certainty equivalent of net returns or the net returns above variable costs (NRVC) less the product of Pratt risk aversion function coefficient and the variance of net returns (σ^2_y). The Pratt risk aversion coefficient is calculated as per methods enumerated by McCarl and Bessler. Ten levels of risk preferences were used for the analysis in the study.

The set of constraints include: Constraint (1) defines a land resource limitation. The farm is restricted to operate on 1,350 acres of cultivable land, derived by rounding the average tillable acres for an Ohio valley grain farm of 1,346 ac up to 1,350 acres (Morgan). Constraint (2) defines the labor constraint across three different states of suitable days for fieldwork and restricts only labor from own resources is used. Constraint (3) is a balancing constraint, which ensures that produce from a certain enterprise E is restricted by the expected yield per acre of that enterprise.

Constraint (4) defines the total purchases by enterprise, operation, and management option. These are estimated using per acre input requirement, total acres under production and agronomic strategy (e.g. plant population). OPER is a matrix of agronomic operations by crop and ensures that these operations are performed sequentially according the date of crop planting. Constraint (5) is a crop rotation constraint reflecting the management practice in the locale. Constraint (6) sets up the initial balance requiring that total bushels of crop enterprise E that are stored or sold cannot exceed the amount produced for the initial week. Constraint (7) determines the marketing flow of crop produce across weeks, requiring that the sum of total sales and total stored for each crop in any week cannot exceed the sum of amount produced in that week and storage from past weeks. Constraint (8) determines the ending balances and makes sure that all crop stored are sold by the end of the year.

Constraint (9) defines the NRVC balances across N yields and N1 prices. STORCOST is a series of storage costs that depend on the crop output prices. STORCOST is generated across R price states. The procedure for arriving at the storage costs was derived from Purdue extension resources. The formulation of the storage costs includes consideration of costs for handling, shrinkage, pest and disease control. Constraint (10) estimates the net revenues above variable costs in the chosen crop enterprise.

The next section presents the results and discussion for the Base and Mean-Var scenarios across four levels of risk preferences. While results across 10 levels of risk preferences were generated, it was considered appropriate to consider four levels alone to highlight the significant findings and in the interest of brevity. The results are presented under four broad sub-heading addressing the issues of farm profitability, cropping strategy and alternative production strategy, management options and impact of storage option.

Results and Discussion

a. Farm Profitability across Risk Aversion under Climatic Change

Producers earned more net returns accompanied with a reduction in C.V. of net returns under the climatic change scenario compared to the Base scenario. While risk neutral producers under the latter case received mean NRVC of $194,576 with an accompanying C.V. of 95%, their counterparts under climatic change received mean NRVC of $214,336 with a C.V. of 93%. These figures imply increases in mean NRVC by 10.15% with a lowering of the C.V. by 2%. Table 1 presents the summary of economic results across scenarios.

However, the increase in the net returns masks the increase in revenue risk under climatic change. This is represented by an increase in the standard deviation of net returns under the Mean-Var scenario. For comparison, risk neutral standard deviation under the Base scenario and the Mean-Var scenario were $185,750 and $198,359 respectively. Other indicators include a decrease in the range of profits under climatic change. Risk neutral mean NRVC under the Base scenarios ranged from a maximum profit of $576,114 to losses of $144,383 comparing to maximum profits of $542,534 and losses of $152,117 under climatic change indicating a movement to greater range of losses under climatic change.

The risk neutral optimal crop mix did not change under the two scenarios considered with 33% of land allotted to corn and remaining to single crop soybean. The indication is that increases in profitability are primarily due to increase in crop enterprise yield combinations under climatic change especially soybean. Soybean yields, recorded increases of up to 15% under the Mean-Var scenario with little change in corn yields.

Positive tradeoffs between mean NRVC and variance in net returns kept net returns under risk aversion lower than the risk neutral case. Risk averse producers in the Mean-Var scenario also enjoyed the general increase in mean profits noticed under risk neutral case. However, the degree of increase in net returns was not as impressive under risk aversion. High-risk averse producers under Mean-Var scenario, for example, recorded only 7.66% increase from Base case mean NRVC's. The C.V. in net return under climatic change was insensitive to increases in risk aversion and remained at around 90% across risk aversion levels. This indicates that producers were not gaining many avenues to increase their certainty of revenues. Standard deviation of net returns, as noticed under the risk neutral level, was higher than the Base under all Mean-Var risk aversion levels. The direction of the range of profits was more in the positive range under Mean-

Var risk aversion levels compared to the Base. This is mainly because risk averse producers in the quest to reduce variance were moving out of high risk crop combinations thus eliminating some of the bad year combinations.

Optimal crop mix under risk aversion paralleled results obtained under risk neutrality. Wheat or double cropped soybean, which could be a more stable combination under some cases, failed to enter any of the risk averse combinations. Producers under extreme risk aversion, however, resorted to elimination of land from cultivation as a means of risk management. For example, under moderate and high risk aversion only 41% and 27% of the total land was cultivated in both scenarios.

b. Cropping Strategy under Climatic Change

Alternative crop production choices under climatic change exhibited a general movement towards later planting dates and higher maturity groups for the optimal crop choices. The sets of optimal choices exhibit rational producers taking advantage of the longer growing season and adapting to increased temperatures under climatic change. Moreover, the degree of adaptation strategies was noticed to a greater degree under the risk averse cases.

Corn planting under the Mean-Var scenario was generally confined to an earlier periods of the 13th –15th weeks compared to the Base scenario where it extended from the 14th to 21st week. Risk neutral producers under Mean-Var scenario split corn planting between the 14th (42%) and 15th (58%) week compared to the 14th (21%) and 16th (79%) week under the Base case, thus not exhibiting any major change in planting strategy. However, under risk aversion, planting times under the two scenarios were distinctly different. The Base scenario risk averse producers resorted to later planting dates to manage risk while earlier planting dates were noticed under the Mean-Var scenario. Specifically, under the Base scenario, the low risk averse producer had corn planting on the 16th(40%) and 21st (60%) weeks while all of moderate and high risk producers planted corn in the 21st week. In the case of climatic change, low risk averse producers had corn planting in 13th (47%) and 14th (53%) weeks while high risk producers chose a combination of 13th (50%), 14th (22%) and 15th (28%) weeks for corn plantings.

Soybean planting under climatic change followed a preference to later planting dates with not much change in the overall planting period compared to the Base scenario. Under both scenarios soybean planting was confined between 17th until the 25th week. However, risk averse producers under climactic change had soybean planting in 17th week and each week from 21st until 25th week compared to a splitting of soybean planting mainly between 17th and 25st week in the Base scenario. With an increase in risk aversion in the Mean-Var scenario, a greater percentage of the soybean planted moved to later planting days while maintaining the general set of planting date choices. Under low level of risk aversion the 22nd week accounted for 24% of all soybean planted. This increased to 42% under moderate and 48% under high levels of risk aversion.

The general increase in temperature expected under global climatic change called for a movement to higher maturity groups from the Base scenario. This adaptation choice was noticed in case of soybean through a movement towards MG 4 and MG 5 soybean maturity groups under climatic change. For example, moderate risk averse producers under the Base scenario chose a combination of MG 3 (22%) and MG 4(78%), which was replaced by MG 4(48%) and MG 5 (52%) under climatic change. Under both scenarios, with an increase in risk aversion, there was an increase in the crop acreage under the lower of maturity groups cultivated in the optimal. This corresponds to the movement to later planting dates mentioned earlier with increase in risk aversion. Table. 2 presents a summary of alternative production strategies under the two scenarios.

c. Management Options under Climatic Change

The decision on how to perform the required crop operations is a critical adaptation strategy when considering the inclusion of the suitable field day risk in the current design. Recall that 3 different states of suitable field days were incorporated in stage 1 of the model constraining the availability of own labor for performing the required crop operations. The producer however had the option of custom hiring field operations to relieve herself of the labor constraint. The crop planting dates is the driving decision behind the management option to custom hire or use own resources. This is because crop planted in a certain week demands crop operations being performed in a certain sequence and in certain week. Earlier planting dates would require earlier crop operations in general (pre-emergence and post emergence spray, fertilization, planting etc.). Therefore, the planting week will serve as a natural reference point for the discussion.

Tables 3 and 4 present the average acreage by operation and management option across scenarios and risk preference level for soybean and corn respectively. In general, there was an increase in demand for custom hiring of field operations under climatic change. Additionally, the planting strategy employed under climatic change require the performance of several operations in a short window of time. Unlike the Base scenario, where risk aversion led to later corn planting, the strategy under climatic change was earlier planting. The earlier range of corn planting under the Mean-Var scenario shifted (13^{th} to the 15^{th} week). This implies hectic corn operations from the 9^{th} to the 15^{th} week across all levels of risk preference with competing soybean operations during that period. Thus, more custom hiring is needed to handle competing crop operations demand, mostly planting, under the Mean-Var scenario.

The increase in demand for custom hiring is illustrated using risk neutral corn planting as an example. Historically, risk neutral corn was planted during the 14th and 16th weeks and involved a mere 7% under custom hired acreage on average. Under climatic change a similar scenario resulted in average custom hired corn planting increasing (45%), mostly because of a very busy 15th week. Both scenarios showed some similarities in that both preplant and post plant corn fertilization was wholly custom hired and all corn harvest and corn hauling operations was wholly self performed. In the former case, custom hiring demand arises from a need to allocate labor to both pre-emergent spray and fertilization operations during the same week. Harvest and hauling operations, which occur relatively late in the cropping period, do not have any other operations competing for own labor and thus do not need custom hired operations. Furthermore, pre-emergent and post emergent corn spraying operations under both scenarios involved about 33% under custom hiring each.

With risk aversion, little change to the trends noticed under risk neutrality was made. Corn planting choice continued to be the significant difference between the two scenarios. Under the Base scenario, the movement to later planting dates (16th and 20th weeks) meant that there was no need for any custom planted corn. However, Mean-Var case where corn continued to be planted from 13th to 15th week required about 33% of the acreage to be custom planted across levels of risk aversion. Another notable point attributed to planting all corn in the 21st week under Base scenario moderate and high risk aversion levels, is the lack of any custom hiring for pre-emergent spray operations under those risk preference levels. The remaining choices closely resembled the risk neutral case for each of the scenarios.

Soybean planting, as mentioned earlier, was confined to planting during weeks from 17th week to 25th week under both scenarios. However, the Base scenario was essentially a split planting with most of the planting done during the 17th week (>80%) and the rest in the 25th week. Under climatic change a greater diversity in planting was noticed with significant planting during the 21st, 22nd and 23rd week. This would imply some overlap in labor demand calling for increased custom hiring under climatic change. This was indeed the case with increased demand for custom hiring for most operations under the Mean-Var scenario. For example, risk neutral soybean under the Base scenario involved 16% of the acreage being custom planted whereas under climatic change this increased to about 35% being custom planted. Similar number for pre-emergent and post emergent soybean spraying operations reveal around 74% and 30% of the acreage being custom hired respectively under climatic change. Fertilizer application was wholly custom hired and hauling wholly using own resources under both scenarios. With increase in risk aversion, the demand for custom hiring fell under both scenarios. In fact, moderate and high risk averse producers under the Base scenario had need for custom hiring only to perform pre emergent spraying and fertilizer application. Climatic change continued to show a need for custom hiring for planting as well as soybean spraying and fertilizer application.

In summary, the analysis suggests that need for custom hired operations increases under climatic change. The underlying reason being a decrease in the number of suitable field days during the critical periods of crop operations and the nature of adaptation chosen by the producer. In the case of corn, a movement to earlier set of planting dates causes the higher demand for custom hiring. Whereas in the case of soybean, diversification in planting dates creates a need for custom hiring. For both crops, the low and moderate risk aversion levels employ the avenue to adapt to climatic change. The high risk producers choose a combination of decreasing cultivated acreage and later planting dates to adapt to the climatic shocks.

e. Marketing Decisions under Climatic Change

Producers may store crop produce from the week of hauling until the end of the year at a given cost thereby providing additional avenues to manage risk. Naturally, the time of hauling operation and quantity of produce hauled are critical factors in deciding both setting the storage and selling period as well as the quantity stored. Summary of crop marketing strategies are provided in Tables 5 and 6 for soybean and corn respectively.

The crop marketing decisions for corn revealed a staggered sales and storage approach under climatic change. Corn producers under climatic change had more selling and storage weeks compared to the Base scenario. For example, risk neutral producers under the base scenario stored all of the corn hauled in the 37th week untill the 40th week for sales in that week. Under Mean-Var scenario, corn hauled in the 36th week was stored until the 47th week, with 78% of the produce sold in 48th week and remaining 22% sold equally in 49th and 50th week.

With risk aversion, a greater need for storage was evident by greater number of weeks under the storage decision compared to risk neutral case under both scenarios. Risk averse producers, in other words, were willing to pay the cost of storage for lower variance in net returns. Moreover, the strategy of storing corn produce longer and staggering corn sales continued with risk aversion under climatic change. For example, risk averse producers under the Base scenario primarily engaged in the uniform strategy involving about 97% of corn sales in the 48th week and the balance in the 52nd week. Under climatic change with risk aversion, corn sales were carried out in the 48th (73%), 49th (9%), 50th (11%) and 52nd (7%) weeks. In addition to multiple selling weeks under climatic change, the decision also involved multiple storage weeks resulting from earlier corn planting. Recall that under risk aversion, corn planting moved to an earlier set of planting dates under climatic change implying an earlier harvest and more storage.

Soybean storage did not enter the optimal choice for risk neutral producers under either scenario. Soybean under climatic change had more sales weeks compared to the Base scenario considering risk averse producers. However, risk averse producers under Base scenario have more involved weeks for storing soybean produce. This is mainly attributed to the soybean hauling schedule wherein most hauling operations took place in 32nd, 33rd and 41st week under the Base scenario. Greater diversity of planting dates resulted in multiple hauling for Mean-Var producer. Base scenario producers under risk aversion has sales in weeks 32nd, 33rd, 48th and 51st weeks while Mean-Var producers sole soybean in 33rd, 38th, 40th 48th and 51st weeks. The Producer under Mean-Var scenario also had more soybean produce to market as a result of increased yields due to climatic change. In summary, both corn and soybean marketing strategies under climatic change involved additional sales weeks compared to the Base scenario.

Conclusions

The main objective of the paper was to present a realistic model to represent the farm production risk under climatic change and study the nature of adaptation across levels of risk preference. A two-stage DSSP approach is employed with uncertainties stemming from crop yield, suitable field days and crop price. The producer may adapt to climate change through alternative production practices, custom hiring and crop storage. The unique feature of the paper, in addition to presenting a comprehensive framework, is the modeling of future price series as a mean reverting jump diffusion process. The price simulation provided for 3 states of future stochastic price series.

In general, economic results suggest benign impact due to climatic change with increased profitability and no major change in the C.V. in net returns. However, the underlying variability in net returns tends to increase under climatic change suggesting potentially a riskier environment. Producers are able to manage this risk primarily due to the range of adaptation avenues that are modeled in the study. The mode of adaptation under climatic change was directed to take advantage of the longer growing season as well as higher temperature experienced. This led to a general shift to earlier corn planting dates and greater range of soybean planting dates in climatic change. Producers under climatic change also employed higher maturity groups that can tolerate the higher temperature. The ability to custom hire field operations provided a reprieve to the producers to manage the decrease in suitable field days experienced under climatic change. Custom hiring of field operation was primarily employed for crop operations that occurred early in the crop growth period including spraying and planting operations. Climatic change led to producers staggering crop sales to manage the risk in stochastic prices. It is clear that given a realistic set of adaptation strategy, producers will be able to efficiently adapt to shocks due to climatic change and actually perform better than historically.

There are some shortcomings in the study that need to be addressed. First, there is need to include the impact of CO_2 fertilization in the crop yield estimate under climatic change. Secondly, it would be preferable to include more sources of production risk in the model. This could include risks due to disease, pests, weeds, etc. to be modeled. Thirdly, it is important to consider changes in technology and human resources that would provide further avenues for adaptation. The present study provides an initial starting point for more detailed and realistic scenarios that account for a realistic picture of farm level decisions under climatic change.

Table 1. Summary of Net Returns and Management Strategy Results by Risk Attitude across Scenarios

Section I. Base Case

	Levels of Risk Preference			
Component	Risk Neutral	Low Risk	Moderate Risk	High Risk
Mean ($)	194,576	134,191	78,606	51,396
Max ($)	576,114	354,757	204,934	133,997
Min ($)	-144,383	-99,756	-57,192	-37,395
Std. Dev. ($)	185,750	125,687	73,267	47,905
C.V.(%)	95	94	93	93
% of Profit Max.	100.00%	68.97%	40.40%	26.41%
Soybean acreage	900	637	370	242
Corn acreage	450	318	185	121

Section II. Mean-Var Case

	Levels of Risk Preference			
Component	Risk Neutral	Low Risk	Moderate Risk	High Risk
Mean ($)	214,336	146,748	84,544	55,333
Max ($)	542,534	374,768	215,116	140,565
Min ($)	-152,117	-104,410	-59,660	-38,957
Std. Dev. ($)	198,359	131,974	75,931	49,665
C.V. (%)	92.55	89.93	89.81	89.76
% of Profit Max.	100.00%	68.47%	39.44%	25.82%
Soybean acreage	900	644	368	240
Corn acreage	450	322	184	120

* Risk Neutral : Z = 50% Slight Risk : Z = 65% Moderate Risk : Z = 75% High Risk : Z= 85%

Table 2. Summary of Alternative Production Practices across Scenarios (%)

Section I. Planting Dates

		Base Case				Mean_Var case			
Crops	Planting Weeks	Risk Neutral	Low Risk	Mod. Risk	High Risk	Risk Neutral	Low Risk	Mod. Risk	High Risk
Corn	13						47	50	50
	14	21				42	53	49	22
	15					58		1	28
	16	79	40						
	21		60	100	100				
Soybean	17	81	83	98	98	89	33	25	26
	18	19				11			
	19								
	21						24	42	48
	22						27	23	10
	23						6	10	15
	25		17	2	2		10		

Section II. Plant Population

Crop	Plant Pop.	Risk Neutral	Low Risk	Mod. Risk	High Risk	Risk Neutral	Low Risk	Mod. Risk	High Risk
Corn	Low	79	100	100	100				
	Medium						53	49	22
	High	21				100	47	51	78
Soybean	R092		100	100	100		100	100	100
	R093	100				100			

Section III. Maturity Groups

Crop	Maturity Groups	Risk Neutral	Low Risk	Mod. Risk	High Risk	Risk Neutral	Low Risk	Mod. Risk	High Risk
Corn	LATE	100	100	100	100	100	100	100	100
Soybean	MG3	33	17	22	22				
	MG4	67	83	78	78	33	60	48	36
	MG5					67	40	52	64

Table 3. Summary of Soybean Operations Choices across Risk Attitude Levels and Scenarios

		Levels of Risk Preference							
		Risk Neutral		Low Risk		Moderate Risk		High Risk	
Operation/Scenario		***Base***	***Mean-Var***	***Base***	***Mean-Var***	***Base***	***Mean-Var***	***Base***	***Mean-Var***
Planting	OWN	760	588	620	561	370	325	242	207
	HIRE	140	312	17	84	0	43	0	33
Pre-emergent spray	OWN	558	233	424	402	247	258	161	172
	HIRE	342	667	212	242	123	111	81	68
Post emergent spray	OWN	784	632	588	509	370	273	242	168
	HIRE	116	268	49	135	0	95	0	72
Fertilizer application	OWN	0	0	0	0	0	0	0	0
	HIRE	900	900	637	644	370	368	242	240
Harvest	OWN	900	827	637	644	370	368	242	240
	HIRE	0	73	0	0	0	0	0	0
Hauling	OWN	900	900	637	644	370	368	242	240
Total Hired		**1,498**	**2,220**	**915**	**1,105**	**493**	**617**	**323**	**413**
Total Own		**3,902**	**3,180**	**2,269**	**2,760**	**1,727**	**1,592**	**1,129**	**1,027**

Table 4. Summary of Corn Operations Choices across Risk Attitude Levels and Scenarios

		Levels of Risk Preference							
		Risk Neutral		Low Risk		Moderate Risk		High Risk	
Operation/Scenario		***Base***	***Mean-Var***	***Base***	***Mean-Var***	***Base***	***Mean-Var***	***Base***	***Mean-Var***
Planting	OWN	418	245	318	215	185	123	121	80
	HIRE	32	205	0	107	0	61	0	40
Pre-emergent Spray	OWN	300	300	212	215	185	123	121	80
	HIRE	150	150	106	107	0	61	0	40
Post Emergent Spray	OWN	300	300	212	215	123	123	81	80
	HIRE	150	150	106	107	62	61	40	40
Pre-Plant Fertilizer	OWN	0	0	0	0	0	0	0	0
	HIRE	450	450	318	322	185	184	121	120
Post Plant Fertilizer	OWN	0	0	0	0	0	0	0	0
	HIRE	450	450	318	322	185	184	121	120
Harvest	OWN	450	450	318	322	185	184	121	120
	HIRE	0	0	0	0	0	0	0	0
Hauling	OWN	450	450	318	322	185	184	121	120
Total Hired		**1,232**	**1,405**	**848**	**965**	**432**	**551**	**282**	**360**
Total Own		**1,918**	**1,745**	**1,378**	**1,289**	**863**	**737**	**565**	**480**

Table 5. Summary of Soybean Marketing Strategies across Risk Attitude Levels and Scenarios

Levels of Risk Preference																
	Risk Neutral				**Low Risk**				**Moderate Risk**				**High Risk**			
Weeks	***Base***		***Mean-Var***		***Base***		***Mean-Var***		***Base***		***Mean-Var***		***Base***		***Mean-Var***	
	SELL	*STORE*	*SELL*	*STORE*	*SELL*	*STORE*	*SELL*	*STORE*	*SELL*	*STORE*	*SELL*	*STORE*	*SELL*	*STORE*	*SELL*	*STORE*
32	10,790				3,910				2,862	60			1,871	39		
33	16,325		12,329		13,993	1,709	9,032		7,878	2,673	3,909		5,147	1,753	2,623	
34	6,157		22,020			1,709				2,673				1,753		
35			3,993			1,709				2,673				1,753		
36						1,709				2,673				1,753		
37						1,709				2,673				1,753		
38						1,709	2,995	10,217		2,673	2,747	6,929		1,753	1,738	4,009
39						1,709		10,217		2,673		6,929		1,753		4,009
40						1,709	1,940	9,756		2,673	1,409	7,000		1,753	927	4,562
41						5,329		9,756		2,915		7,000		1,911		4,562
42						5,329		12,202		2,915		7,000		1,911		4,562
43						5,329		12,202		2,915		7,000		1,911		4,562
44						5,329		12,202		2,915		7,000		1,911		4,562
45						5,329		12,202		2,915		7,000		1,911		4,562
46						5,329		12,202		2,915		7,000		1,911		4,562
47						5,329		12,202		2,915		7,000		1,911		4,562
48					76	5,253	3,753	8,449	5	2,910	2,151	4,849	3	1,907	1,406	3,156
49						5,253		8,449		2,910		4,849		1,907		3,156
50						5,253		8,449		2,910		4,849		1,907		3,156
51					5,253		8,449		2,910		4,849		1,907		3,156	

Table 6. Summary of Corn Marketing Strategies across Risk Attitude Levels and Scenarios

Levels of Risk Preference																
	Risk Neutral				**Low Risk**				**Moderate Risk**				**High Risk**			
Weeks	***Base***		***Mean-Var***		***Base***		***Mean-Var***		***Base***		***Mean-Var***		***Base***		***Mean-Var***	
	SELL	*STORE*	*SELL*	*STORE*	*SELL*	*STORE*	*SELL*	*STORE*	*SELL*	*STORE*	*SELL*	*STORE*	*SELL*	*STORE*	*SELL*	*STORE*
34							676	13,383			189	8,357			57	5,573
35	9,627		17,607				1,697	27,568			562	16,076			251	7,718
36				24,318				27,568				16,377				10,859
37		35,711		24,318		12,721		27,568				16,377				10,859
38		35,711		24,318		12,721		27,568				16,377				10,859
39		35,711		24,318		12,721		27,568				16,377				10,859
40	35,711			24,318		12,721		27,568				16,377				10,859
41				24,318		12,721		27,568				16,377				10,859
42				24,318		31,844		27,568		18,436		16,377		12,054		10,859
43				24,318		31,844		27,568		18,436		16,377		12,054		10,859
44				24,318		31,844		27,568		18,436		16,377		12,054		10,859
45				24,318		31,844		27,568		18,436		16,377		12,054		10,859
46				24,318		31,844		27,568		18,436		16,377		12,054		10,859
47				24,318		31,844		27,568		18,436		16,377		12,054		10,859
48			19,058	5,260	31,246	599	20,017	7,551	17,934	502	12,033	4,344	11,726	328	7,953	2,907
49			2,641	2,619		599	2,420	5,130		502	1,385	2,959		328	907	2,000
50			2,619			599	3,116	2,014		502	1,792	1,167		328	1,173	827
51						599	2,007	7		502	1,148	19		328	813	14
52					599		7		502		19		328		14	

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