

Hedging Crop Risk with Weather Index and Individual Crop Insurance

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Abstract

While individual crop insurance and the potential weather index are valuable instruments in managing agricultural risk, the problems of asymmetric information (moral hazard and adverse selection) in individual crop insurance induce large transaction cost and imperfect correlation between individual realization and specific weather event creates unfavorable basis risk. This paper provides a theoretical analysis for the optimal portfolio of weather index and individual crop insurance in farm level under the mean-variance framework and stresses the impacts of risk aversion level, transaction cost, and basis risk. An empirical application of corn farms using data in Todd county of Kentucky is applied to.

Introduction

Agriculture is particularly prone to risk among economic activities. Risk-reducing practices involve behavior that is performed before and after the risky event, aimed to securing sources of remedial income in the event of loss. Dillon has provided evidence that production risk can be reduced through crop diversification, varied planting data, and alteration across different maturity class. However, these practices have certain limitations and ultimately reduce farm profits in the long run.

Crop insurance and weather index based products can be valuable instruments in managing production risk. For example, farmers can protect crop yields loss using the individual crop insurance when the yield is less than a predetermined target, or potential weather derivatives when the underlying weather index is below the pre-specified strike. Individual crop insurance provides indemnities based on the realized individual yields, that is, the payment can be incurred by weather-related loss and other unavoidable perils, or even bad management.

Meanwhile, weather index offers payment that relies on some specific weather events, that is correlated, but not 100%, with the individual crop yields. Therefore, the problems of asymmetric information (moral hazard and adverse selection) induce large transaction cost (e.g., administration cost, monitoring cost, inspection cost) while the imperfect correlation between individual realization and specific weather event creates the basis risk².

This paper provides a theoretical model and empirical application for the optimal portfolio of individual crop insurance and weather index and highlights the trade-off between transaction costs and basis risk under a mean-variance framework. Four parts are included in this article. First, the problem is addressed along with a review of the literature. Second, the theoretical framework to model the simultaneous demand for individual crop insurance and weather index is developed using a mean-variance model. Third, an empirical application is provided using data from rainfall and corn yields in Todd county of Kentucky. Fourth, conclusions and recommendations are developed.

Background

Crop insurance has been a part of U.S. federal policy for a long time. Since 1938, the federal government has included crop insurance programs as part of the set of policies for the agricultural sector. In 2002, the estimated number of crop insurance policies exceeded 1.25 million with total liabilities exceeding \$37 billion (Ker and Ergun). The transaction cost involved in crop insurance program is relatively high because of the asymmetric information (moral hazard and adverse selection) (Goodwin; Skees, 2001a; Skees; Smith and Goodwin; Skees and Reed), thus federal government has to subsidize this program for its viability. For example,

² Actually, individual crop insurance is also inherent with the basis risk because of the sampling error and measurement error, but this point is beyond the scope of our paper.

Goodwin estimated that the loss ratio is approximately 1.88 during 1981-99 periods for the crop insurance program of U.S.

Agricultural production is sensitive to weather variations, especially to varying levels of temperature or precipitation. Rosenzweig and Binswanger utilize panel data from rural South India investments, wealth and rainfall to measure the riskiness of farmers' investment portfolios in terms of their sensitivity to weather variation. Their results show that the asset portfolios are significantly influenced by the degree of rainfall variability. In particular, farmers in riskier environments select portfolios of assets that are less sensitive to rainfall variation. Furthermore, the intra-temporal variation of large-area crop yields is mainly caused by weather variation and systemic risk explains a large portion of the variability of the producer's income.

The application of weather based products in agriculture is potent though it is still in fledging stage and only a few successive weather trades have been completed for agricultural users. For example, Turvey reported that Agricorp, the crown corporation charged with providing crop insurance to Ontario farmers, have initiated a pilot program for forage insurance with a rainfall insurance plan in the spring of 2000. Skees (2001b) suggested that three classes that link the agricultural risk and weather events have motivate the particular interests: 1) Crop yield risk; 2) Livestock risk; 3) Environment and natural resource risk.

The advantages of index products over the traditional insurance products are free of moral hazard and adverse selection since the indemnity depends on the specified weather variable rather than actual losses such as crop failure. The underwriting of weather index is also less costly since they do not require individual contracts, onsite inspection and loss evaluation. However, producers may have to face a higher level of basis risk, that is, an individual can have a loss and not be paid because the weather variables are not completely correlated with the yield.

Obviously, the decision to purchase insurance or weather index products will be affected by the degree of risk aversion level, the transaction cost insured by individual crop insurance and the basis risk induced by weather index. The objective of this paper is to analyze the optimal portfolio of individual crop insurance and weather index at the farm level and provide the evidences for the trade-off between transaction cost and basis risk across different risk aversion levels of the producers.

Theoretical Analysis

A risk-averse producer faces risks of production, which is contingent upon some weather conditions. Therefore, crop yield can be orthogonally decomposed into two parts. One is systematic risk that comes from adverse weather condition; the other is the idiosyncratic (residual) component which reflects the individual's variability not stemming from weather and uncorrelated with weather conditions. This decomposition is reasonable since systemic risk in agriculture is mainly attributable to the impact of extensively unfavorable weather such as drought or flood, which affects the crop yields of a large geographic region simultaneously.

Therefore, the individual yield³ can be written as

$$(1) \quad \tilde{y}_i = \mu_i + \beta_i(\tilde{w} - w) + \tilde{\varepsilon}_i$$

where $E(\tilde{y}_i) = \mu_i$; $Var(\tilde{y}_i) = \sigma_{\tilde{y}_i}^2$

$$E(\tilde{w}) = w; \quad Var(\tilde{w}) = \sigma_{\tilde{w}}^2$$

$$E(\tilde{\varepsilon}_i) = 0; \quad Var(\tilde{\varepsilon}_i) = \sigma_{\tilde{\varepsilon}_i}^2; \quad Cov(\tilde{w}, \tilde{\varepsilon}_i) = 0$$

$$\beta_i = \frac{Cov(\tilde{y}_i, \tilde{w})}{Var(\tilde{w})}$$

³ The tildes (\sim) denotes a random variables.

Miranda first formalized this framework in designing the optimal area-yield crop insurance. In our model, we decompose the individual crop yield deviation from expectation into a systematic component measured by the deviations of the weather condition (\tilde{w}), and an idiosyncratic component $\tilde{\varepsilon}_i$. The coefficient β_i quantifies the sensitivity of the deviations of crop yield to the deviations of the weather conditions. Here, \tilde{w} can be measured by a unique weather variable, such as precipitation, temperature, or a combination of several related weather variables, such as rainfall or temperature. The optimal decision of this weather index contract will depend on the beta coefficient which measures the sensitivity of individual crop yield to the weather conditions.

Assume the producer is only facing production risk and the output price is normalized to be unity without a loss of generality. The producer can use two instruments to manage production risk: individual crop insurance and weather index. Furthermore, we assume that individual crop insurance is sold at an actuarially unfair price because of high transaction cost while weather index is sold at actuarially fair price. Suppose that the indemnity and premium are both denominated in production units, that is, bushels per acre. Production costs are also ignored in this analysis⁴. For notational convenience, the subscript i has been dropped out within below analysis.

The individual crop insurance is established based on the yield shortfall between the actual harvest yield (\tilde{y}) and the guaranteed yield (y_c). This policy can be described by the couple $[I(\bullet), P]$ where $I(\tilde{y})$ be the indemnity function and P be the premium.

$$(2) \quad I(\tilde{y}) = \text{Max}((y_c - \tilde{y}), 0)$$

$$(3) \quad P = (1 + \lambda)E(I(\tilde{y})) \geq 0$$

where λ be loading factor⁵ and E be the expectation operator. The linear relationship of premium and expected indemnity implies that transaction cost is proportional to claims.

Intuitively, $\frac{\partial P}{\partial E(I(\tilde{y}))} > 1$ if the loading factor is positive, that is, a marginal increase in coverage is costly because the increase in premium would be larger than the increase in expected payment. Meanwhile, subsidized crop insurance can introduce production in external margins since the marginal increase in coverage is relatively cheaper.

The design of the weather index is followed by the European precipitation options proposed by Skees and Zeuli (1999) and it is in the form of puts options. This policy can be described by the couple $[J(\bullet), Q]$ where $J(\tilde{w})$ be the indemnity function and Q be the premium.

$$(4) \quad J(\tilde{w}) = \theta \times \text{Max}((w_c - \tilde{w}), 0)$$

$$(5) \quad Q = E(I(\tilde{w}))$$

where w_c be predetermined weather conditions and θ be the tick (bushel/unit of index).

With the purchase of the individual crop insurance and the weather index, the producer's net revenue can be represented by

$$(6) \quad \tilde{y}^{net} = A\tilde{y} + A'(I(\tilde{y}) - P) + n(J(\tilde{w}) - Q)$$

where A be the total acre of land available, A' is the acre of insured land⁶, $A' \in [0, A]$, and n is the amount of weather index policy purchased by the producer.

The mean of the net revenue is given by

$$(7) \quad E(\tilde{y}^{net}) = A\mu - A'\lambda E(I(\tilde{y}))$$

The variance of the net revenue can be measured by

⁴ If production costs are correlated with the crop yields, then the problem becomes more complicated

⁵ Actually, λ can even be a negative number because of high subsidies in crop insurance program in U.S. (Skees, 1999; Goodwin, 2001). Gollier (2003) estimated the loading factor around 0.3 for the casualty insurance case.

$$(8) \quad Var(\tilde{y}^{net}) = A^2 \sigma_{\tilde{y}}^2 + A^2 \sigma_{I(\tilde{y})}^2 + n^2 \sigma_{J(\tilde{w})}^2 + 2AA' Cov(\tilde{y}, I(\tilde{y})) + 2AnCov(\tilde{y}, J(\tilde{w})) + 2A'nCov(I(\tilde{y}), J(\tilde{w}))$$

From the equality, $\tilde{y}_i = \mu_i + \beta_i(\tilde{w} - w) + \tilde{\varepsilon}_i$. Assume that the non-systemic component $\tilde{\varepsilon}_i$ and weather index \tilde{w} are conditionally independent (a mild assumption given that they are uncorrelated by definition). Then $\tilde{\varepsilon}_i$ and $J(\tilde{w})$ are uncorrelated. We can rewrite

$$(9) \quad Cov(\tilde{y}, J(\tilde{w})) = \beta_i Cov(\tilde{w}, J(\tilde{w}))$$

Intuitively, we have, $Cov(\tilde{w}, J(\tilde{w})) < 0$, and $Cov(I(\tilde{y}), J(\tilde{w})) > 0$.

The mean-variance (EV) results have been shown to be consistent with the expected utility hypothesis under some conditions (Freund ; Meyer). The elicited set of alternatives is what is known as the “efficient frontier” for a decision maker that is assumed to have a positive preference for income and negative preference for variance. The optimal solution depends on the decision maker’s preference tradeoffs between expected returns and variance of returns, that is, risk aversion. The model can provide tractable solutions to many theoretical problems in risk analysis, but has limitations in that it assumes constant absolute risk aversion (CARA) and normality in density function to be consistent with expected utility theory.

Under the framework of EV model, the producer chooses a portfolio of the acre of insured land and the amount of weather index policy to maximize utility with risk adverse behavior. The objective function is given by

$$(10) \quad \underset{n, A'}{Max} U^{net} = E(\tilde{y}^{net}) - \frac{1}{2} \phi * Var(\tilde{y}^{net})$$

Where ϕ is CARA coefficient.

The first order condition gives us

⁶ Assume that a producer can insure part of his own land based on his optimal decision.

$$(11) \quad \frac{\partial U^{net}}{\partial n} = -\frac{1}{2}\phi 2n\sigma_{J(\tilde{w})}^2 - \frac{1}{2}\phi 2A\beta_i \text{Cov}(\tilde{w}, J(\tilde{w})) - \frac{1}{2}\phi 2A'_i \text{Cov}(J(\tilde{w}), I(\tilde{y})) = 0$$

$$(12) \quad \frac{\partial U^{net}}{\partial A'} = -\lambda E(I(\tilde{y})) - \frac{1}{2}\phi 2A'\sigma_{I(\tilde{y})}^2 - \frac{1}{2}\phi 2A \text{Cov}(\tilde{y}, I(\tilde{y})) - \frac{1}{2}\phi 2n \text{Cov}(I(\tilde{y}), J(\tilde{w})) = 0$$

They can be rewritten as

$$(13) \quad n^* = \frac{-A\beta_i \text{Cov}(\tilde{w}, J(\tilde{w}))}{\sigma_{J(\tilde{w})}^2} + \frac{-A'^* \text{Cov}(J(\tilde{w}), I(\tilde{y}))}{\sigma_{J(\tilde{w})}^2}$$

$$(14) \quad A'^* = \frac{-\lambda E(I(\tilde{y}))}{\phi \sigma_{I(\tilde{y})}^2} - \frac{A \text{Cov}(\tilde{y}, I(\tilde{y}))}{\sigma_{I(\tilde{y})}^2} - \frac{n^* \text{Cov}(J(\tilde{w}), I(\tilde{y}))}{\sigma_{I(\tilde{y})}^2}$$

It follows from (13) and (14), we have

Proposition 1.

The optimal amount of weather index purchased is decreasing with the acre of land insured. Thus we can deduce that weather index can act as a substitute for individual crop insurance.

Furthermore, we can define $\rho = \frac{\text{Cov}(J(\tilde{w}), I(\tilde{y}))}{\sigma_{J(\tilde{w})}\sigma_{I(\tilde{y})}}$, with $\rho \in (0,1)$, a measure of the

correlation between individual crop insurance payment and weather index payment. Clearly, ρ is a function of beta coefficient β . Then, the above two equations can be rewritten as

$$(13') \quad n^* = -\frac{A\beta_i \text{Cov}(\tilde{w}, J(\tilde{w}))}{\sigma_{J(\tilde{w})}^2} - A'^* \rho \frac{\sigma_{I(\tilde{y})}}{\sigma_{J(\tilde{w})}}$$

$$(14') \quad A'^* = \frac{-\lambda E(I(\tilde{y}))}{\phi \sigma_{I(\tilde{y})}^2} - \frac{A \text{Cov}(\tilde{y}, I(\tilde{y}))}{\sigma_{I(\tilde{y})}^2} - n^* \rho \frac{\sigma_{J(\tilde{w})}}{\sigma_{I(\tilde{y})}}$$

Suppose $A' = 0$, that is, only weather index is available for hedging production risk. The optimal number of weather index purchased is given by

$$(15) \quad n^* = -\frac{A\beta_i \text{Cov}(\tilde{w}, J(\tilde{w}))}{\sigma_{J(\tilde{w})}^2}$$

If we define $\beta_c = -\frac{\sigma_{J(\tilde{w})}^2}{2\text{Cov}(\tilde{w}, J(\tilde{w}))} > 0$ as the critical beta, then, we have

$$(15') \quad n^* = \frac{\beta_i}{2\beta_c} A \geq 0$$

The critical beta (β_c), determined by the area weather conditions and rising with the targeted weather index (w_c), is invariant among all producers within a given area. It thus follows from (15'):

Proposition 2.

If only weather index with actuarially fair price is available, the producer would always like to choose a fixed and nonnegative amount of weather index policy regardless of his risk aversion level. The optimal amount of weather index policy purchased is completely determined by, and is positively related to his individual beta coefficient β_i and the total acres of land A.

Alternatively, provided that $n=0$, that is, only individual crop insurance is available, the optimal acres of insured land are given by

$$(16) \quad A^* = \frac{-\lambda E(I(\tilde{y}))}{\phi \sigma_{I(\tilde{y})}^2} - \frac{A \text{Cov}(\tilde{y}, I(\tilde{y}))}{\sigma_{I(\tilde{y})}^2}$$

Based on equations (16), we have:

Proposition 3.

- *The producer insures the crop only if $-A \text{Cov}(\tilde{y}, I(\tilde{y})) > \frac{\lambda}{\phi} E(I(\tilde{y}))$ and fully insures*

(that is, $A^ = A$) only if $\frac{\lambda}{\phi} = -\frac{A(\text{Cov}(\tilde{y}, I(\tilde{y})) + \sigma_{I(\tilde{y})}^2)}{E(I(\tilde{y}))}$*

- *Ceteris paribus, the higher the risk averse producer is, the more land the producer would like to insure;*
- *Ceteris paribus, the larger the risk loading factor it is, the less insured land the producer would like to insure. However, the subsidized policy will increase the purchase of crop insurance.*

After rearrange the equation 13` and 14`), the optimal combination of individual crop insurance and weather index under the mean-variance framework is given by

$$(17) \quad n^* = \frac{\rho \lambda E(I(\tilde{y}))}{(1-\rho^2)\phi\sigma_{J(\tilde{w})}\sigma_{I(\tilde{y})}} + \frac{A\rho Cov(\tilde{y}, I(\tilde{y}))}{(1-\rho^2)\sigma_{J(\tilde{w})}\sigma_{I(\tilde{y})}} + \frac{A\beta_i}{2(1-\rho^2)\beta_c}$$

$$= \frac{\rho}{(1-\rho^2)\sigma_{J(\tilde{w})}\sigma_{I(\tilde{y})}} \left(\frac{\lambda E(I(\tilde{y}))}{\phi} + ACov(\tilde{y}, I(\tilde{y})) + \frac{A\beta_i\sigma_{J(\tilde{w})}\sigma_{I(\tilde{y})}}{2\rho\beta_c} \right)$$

$$(18) \quad A^* = -\frac{ACov(\tilde{y}, I(\tilde{y}))}{(1-\rho^2)\sigma_{I(\tilde{y})}^2} - \frac{\lambda E(I(\tilde{y}))}{(1-\rho^2)\phi\sigma_{I(\tilde{y})}^2} + \frac{A\beta_i\rho Cov(\tilde{w}, J(\tilde{w}))}{(1-\rho^2)\sigma_{I(\tilde{y})}\sigma_{J(\tilde{w})}}$$

$$= \frac{1}{(1-\rho^2)\sigma_{I(\tilde{y})}^2} \left(A\beta_i\rho Cov(\tilde{w}, J(\tilde{w})) \frac{\sigma_{I(\tilde{y})}}{\sigma_{J(\tilde{w})}} - ACov(\tilde{y}, I(\tilde{y})) - \frac{\lambda E(I(\tilde{y}))}{\phi} \right)$$

Following Equation 18) and 19), we have proposition 4 as follows:

Proposition 4.

1) As long as $\frac{\lambda E(I(\tilde{y}))}{\phi} + ACov(\tilde{y}, I(\tilde{y})) + \frac{A\beta_i\sigma_{J(\tilde{w})}\sigma_{I(\tilde{y})}}{2\rho\beta_c} > 0$ and

$A\beta_i\rho Cov(\tilde{w}, J(\tilde{w})) - ACov(\tilde{y}, I(\tilde{y})) - \frac{\lambda E(I(\tilde{y}))}{\phi} > 0$, the producer will choose a portfolio of

positive amount of weather index policy and insured land. The decision of purchase depends on the risk aversion level, the loading factor and the level of basis risk.

2) *Ceteris paribus, the higher risk averse the producer is, the more acre of insured land and the less amount of weather index the producer would like to choose, that is, the elasticity of*

the substitution between individual crop insurance and weather index is increasing with producer' risk aversion level.

3) Ceteris paribus, the larger the risk loading factor it is, the less acre of insured land and the more amount of weather index policy the producer would like to choose; However, the subsidized crop insurance will induce the opposite results and can crowd out weather index from the market.

4) The impact of basis risk is complicated since it depends on both of ρ and β_i . Under some conditions⁷, ceteris paribus, the optimal purchase amount of weather index is increasing with high level of basis risk while the optimal acre of land insured is decreasing with basis risk.

Furthermore, we can derive the market enhancing of the combination of individual crop insurance and weather index. The added value of the individual insurance and weather index can be measured by the increasing utility.

$$(19) \quad \Delta U = U^{net}(n^*, A'^*) - U(0,0)$$

It is also possible to compare the cases in which only one of these two instruments is available for the producer. The simultaneous use of weather index and individual crop insurance should be market enhancing, that is, it allows the producer to increase the expected yield for the same level of yield variance or, equivalently, to reduce the yield variance for a given expected yield.

Data and Empirical Results

Data

A dataset of historical corn yields was applied for Todd County in Kentucky. The individual yield data set was a cross sectional time series of actual yields for 28 farmers that

⁷ For example, both ρ and β / ρ is an increasing function of β , a measure of basis risk.

participated in the federal crop insurance program between 1985 and 1994 with a ten years of APH record from the Federal Crop Insurance Corporation. County yield records were obtained from the National Agricultural Statistics Server (NASS).

The yield data was detrended since the trend represents a systematic change in crop yields due to improved technologies and agricultural practices. The detrended yields are given by

$$(20) \quad \text{Adjusted Yield}_t = (\text{Actual yield}_t / \text{Trend yield}_t) \times \text{Forecasted Based Yield}$$

Rainfall data is from the University of Kentucky Agricultural Weather Center and the study utilizes data from 1985 to 1994 in nearest Bowling Green Weather Station. The rainfall is first aggregated in four different critical growth periods based on climate and plant physiology. Weights for these four periods are then assigned through a mathematical programming procedure that maximizes correlation between county yields and rainfall index. The vector of weights is then checked in order to make it consistent with agronomic information. The final value of the index is calculated by summing the values obtained by multiplying rainfall levels in each period by the specific weights assigned to a particular period. The summary is provided in table 1.

The beta coefficients (β_i) are estimated from equation 1. The beta coefficients among the 28 farmers are fit using a nonparametric kernel smoother. Figure 1 presents the smoothed probability density function for these data, suggesting that β_i are bimodally distributed.

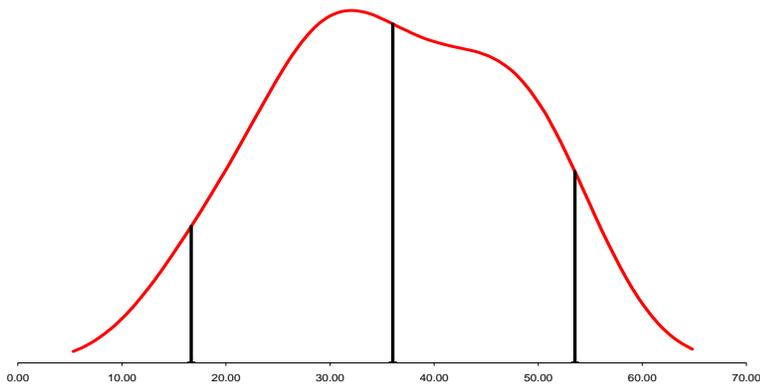


Figure 2: The Kernel Distribution of Beta Coefficients

The critical yield in equation 2) is defined by $y_c = 0.85 \times \bar{y}$ and the critical weather index in equation 4) is defined by $w_c = \bar{w}$. The total land available is fixed at 1,000 acres. The optimal solutions were solved through a MP approach using CONOPT solver. Three relative risk levels are considered in this paper: low risk level, moderate risk level and high risk level. The loading factor is first fixed by .33 in the first three scenarios and then varied in the last scenario to represent different levels of transaction cost. The results of four different scenarios are discussed as follows.

Scenario1: Only Weather Index

The optimal results of n , Y^{net} , and ΔU when only weather index is available for farmers are provided in the table 2. The farms are selected by every other in order of ascending beta value. The results show that the optimal amount of weather index policy is uniquely and positively related to the beta coefficients, regardless of the risk level. Furthermore, the market enhancing (ΔU) is also increasing with the risk level. For example, the increased utilities for 15 farm are 2041, 2915, and 3190 bushels with an fixed amount of 1538 weather index purchased, respectively across low, moderate, and high risk level.

Scenario2: Only Individual Crop Insurance

Table 3 provides optimal results for the insured land provided that only individual crop insurance is available. The results are consistent with our theoretical model that the higher risk level the farmer is, the more land he would like to insure. The increased utilities due to actuarially unfair individual crop insurance for farm 15 are 753 bushels with insuring 635 acres of land for low risk level, 2458 bushels with insuring 956 acres of land, and 4362 bushels with insuring all 1000 acres of land, respectively.

Scenario3: A Portfolio of Weather Index and Individual Crop Insurance

Table 4 shows the optimal choices of a portfolio of weather index policy and insured land. The results are consistent with our expectation and the substitution of crop insurance and rainfall index is obvious. The producers with low risk levels prefer rainfall index due to its low transaction cost while those with high risk levels favor the individual crop insurance because of its low basis risk. The increased utility corresponding to the optimal choices across different risk levels always bring at least the same utility as that corresponding to only using weather index or individual crop insurance. For example, farm 15 chooses 1538 weather index and zero insured land with an increased utility 2041 for the low risk level, 1242 weather index and 236 insured land with an increased utility 2956 for the moderate risk level, and 445 weather index and 871 insured land with an increased utility 4505 for the high risk level.

Across different producers, the basis risk is varied. It is reasonable to assume that a farmer with a high of both β and ρ has a low basis risk. Our results generally support the hypothesis that the producer with a high basis would like to prefer more crop insurance rather than rainfall index. However, the results are not absolutely correct since we can not assume that all farmers are identical except that the basis risk.

Scenario4: Impact of Transaction Cost: Loading Factor

Farm 15 is chosen as a representative for analyzing impacts of changing loading factor. The loading factor is varied between 0 and 1. Figure 2 shows the negative relationship between the loading factor and insured land across different risk levels if only individual crop insurance is available.

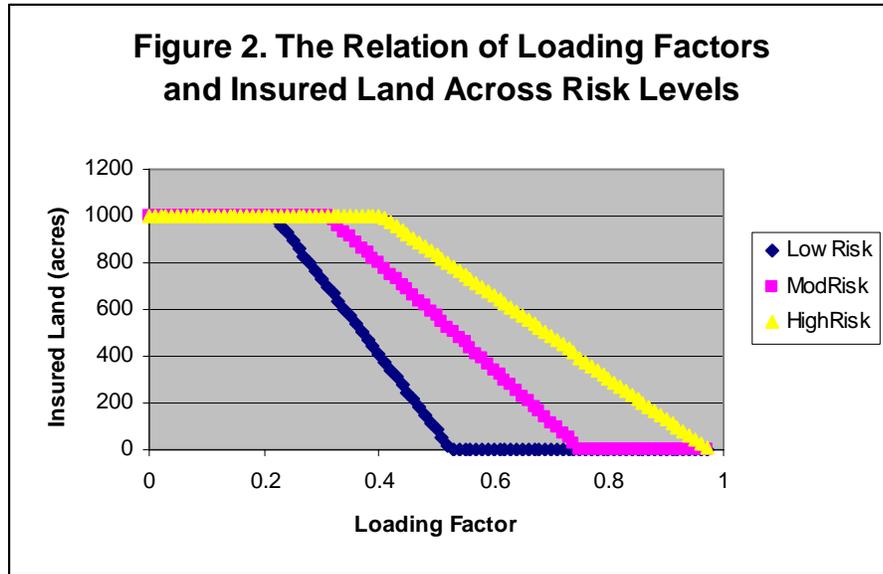
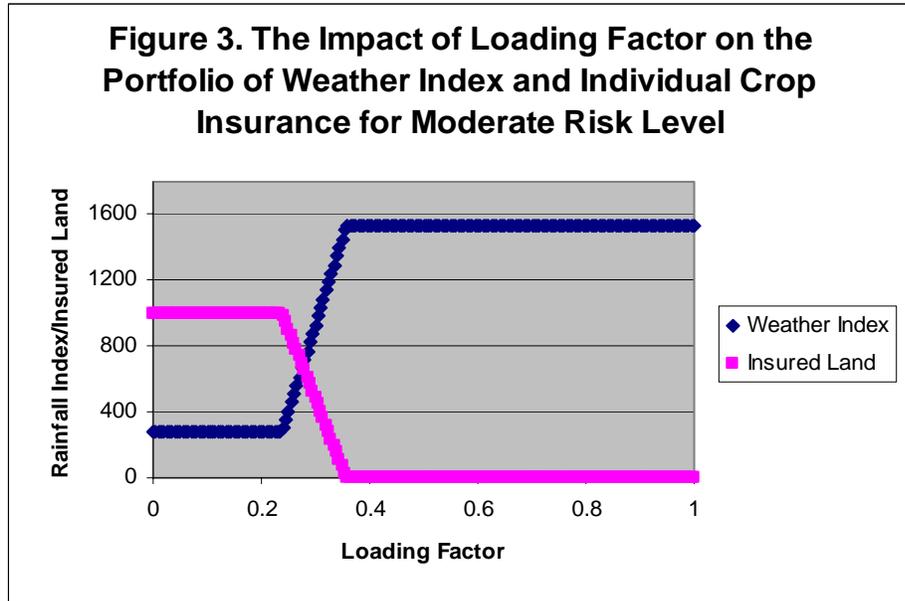


Figure 3 shows the impact of loading factor on the optimal portfolio of rainfall index and individual crop insurance for the moderate risk level. When the loading factor is below 0.24, the producer fully insures his crop and purchases a fixed amount of 282 weather index policy; when the loading factor is beyond 0.355, the producer would like to purchase a up limit of 1538 weather index and insure zero land; when the loading factor is in this interval, the producer would like to trade off the insured land with weather index to maximize his/her utility.



Conclusions

Agriculture is plagued by numerous risks, and risk management is always an important component in the farmers' decision-making. The paper provides a combination of individual crop insurance and innovative weather index as candidates in the portfolio of risk hedging for the producers. The emphasis is to analyze the impacts of the risk aversion level, transaction cost and the basis risk under a mean-variance model.

The results indicate that producers can efficiently manage the risk through a combination of individual crop insurance and weather index and weather index can act as a substitute for the individual crop insurance. The empirical application using the weather and corn yield data from Todd county in Kentucky further demonstrate the substitution of individual crop insurance and weather index and suggest the market enhancing of an optimal portfolio.

We assume that producer is facing with only production risk and only one crop is available. In real world, farmers might select different crops and face up with several sources of risk, such as production risk, price risk, and credit risk. Further research can calibrate our model to several different crops in the portfolio and include the price risk with futures markets.

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Table 1. Design of Weather Index

	Critical Growth Period	Time Span	Weights
1	Establishment	Apr 15-May 12	0.39
2	Vegetative	May 13-June 2	0.26
3	Pollination	June 3 – June 28	0.3
4	Grainfilling	June 29 – August 15	0.05

Table 2: The Optimal Results of Rainfall Index Contract

Farm	Beta	Corr	Low Risk Level			Moderate Risk Level			High Risk Level		
			n	Ynet	deltaU	n	Ynet	deltaU	n	Ynet	DeltaU
1	16.28	0.19	683	126845.7	402	683	126846	574	683	126846	747
3	18.38	0.88	771	105486.3	513	771	105486	732	771	105486	952
5	26.19	0.63	1098	115691.8	1040	1098	115692	1486	1098	115692	1931
7	27.75	0.56	1164	105146	1168	1164	105146	1669	1164	105146	2170
9	29.12	0.79	1221	143536.9	1286	1221	143537	1837	1221	143537	2388
11	31.04	0.70	1302	137470.7	1462	1302	137471	2088	1302	137471	2714
13	33.89	0.89	1421	104847	1742	1421	104847	2488	1421	104847	3235
15	36.68	0.85	1538	107079	2041	1538	107079	2915	1538	107079	3790
17	37.19	0.47	1559	147871	2097	1559	147871	2996	1559	147871	3895
19	43.13	0.87	1808	135085.9	2821	1808	135086	4030	1808	135086	5239
21	43.95	0.92	1843	127284.2	2930	1843	127284	4185	1843	127284	5441
23	47.48	0.92	1991	121109.3	3419	1991	121109	4884	1991	121109	6350
25	49.55	0.73	2077	136019.1	3723	2077	136019	5318	2077	136019	6914
27	52.27	0.87	2191	103267	4144	2191	103267	5919	2191	103267	7695

Table 3. The Optimal Results of Individual Crop Insurance

Farm	Beta	Corr	Low Risk Level			Moderate Risk Level			High Risk Level		
			A1	Ynet	deltaU	A1	Ynet	deltaU	A1	Ynet	deltaU
1	16.28	0.19	0	126169	0	422	126384	45	919	125839	279
3	18.38	0.88	0	104975	0	179	105254	9	725	104545	187
5	26.19	0.63	373	113186	121	836	113449	868	1000	113010	1890
7	27.75	0.56	503	100285	352	1000	100285	2093	1000	100285	4180
9	29.12	0.79	733	139435	845	1000	139435	2806	1000	139435	4878
11	31.04	0.70	443	134836	154	944	134983	1003	1000	134836	2090
13	33.89	0.89	589	101316	575	915	101563	1979	1000	101257	3627
15	36.68	0.85	635	103082	753	956	103260	2438	1000	103082	4362
17	37.19	0.47	792	144489	1233	1000	144489	3089	1000	144489	5031
19	43.13	0.87	670	130959	653	1000	130959	2474	1000	130959	4455
21	43.95	0.92	780	124281	1427	972	124365	3167	1000	124281	5014
23	47.48	0.92	703	116748	966	1000	116748	3002	1000	116748	5212
25	49.55	0.73	778	131413	1231	1000	131413	3590	1000	131413	6049
27	52.27	0.87	716	98038	1256	1000	98038	3754	1000	98038	6449

Table 4. The Optimal Portfolio of Weather Index and Individual Crop Insurance

Farm	Beta	Corr	Low Risk Level				Moderate Risk Level				High Risk Level			
			n	A1	Ynet	deltaU	n	A1	Ynet	deltaU	n	A1	Ynet	deltaU
1	16.28	0.19	683	0	126846	402	670	138	126694	579	625	654	126129	883
3	18.38	0.88	771	0	105486	513	771	0	105486	732	771	0	105486	952
5	26.19	0.63	1098	0	115692	1040	944	243	115039	1530	682	657	113930	2351
7	27.75	0.56	1164	0	105146	1168	634	747	101513	2437	455	1000	100285	4512
9	29.12	0.79	1173	44	143355	1287	150	1000	139435	2833	150	1000	139435	4914
11	31.04	0.70	1302	0	137471	1462	1302	0	137471	2088	959	514	136118	2912
13	33.89	0.89	1421	0	104847	1742	1384	30	104739	2489	390	841	101828	3704
15	36.68	0.85	1538	0	107079	2041	1242	236	106137	2956	445	871	103600	4505
17	37.19	0.47	1280	390	146551	2330	1042	723	145427	4135	914	902	144822	6199
19	43.13	0.87	1808	0	135086	2821	1808	0	135086	4030	1283	465	133167	5381
21	43.95	0.92	1843	0	127284	2930	1843	0	127284	4185	1380	305	126368	5502
23	47.48	0.92	1991	0	121109	3419	1991	0	121109	4884	1991	0	121109	6350
25	49.55	0.73	2077	0	136019	3723	1774	269	134781	5415	1325	667	132949	7686
27	52.27	0.87	2191	0	103267	4144	2191	0	103267	5919	1719	323	101579	7812