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Weather Derivatives and Crop Insurance in China

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Weather Derivatives and Crop Insurance in China

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Abstract

The effectiveness of financial weather derivatives to hedge against risk in agriculture has not been well demonstrated; therefore, this risk hedging instrument has only been slowly adopted. The current study analyzes the hedging efficiency of weather index derivatives for corn production in Northeast China. It has two purposes: (1) to identify potential weather variables, such as cumulative rainfall or growing degree days, that impact corn yields; and (2) to analyze the efficiency of financial weather derivatives under varying strike values, where efficiency is defined in terms of its benefit to farmers. Regression results indicate that cumulative rainfall is important for crop production in the study region, and that, under some circumstances, it is efficient to use a weather-indexed financial derivatives to hedge the corresponding risk.

Key words: financial weather derivatives, climate risk, corn production, rainfall

Introduction

In countries where farmers could access traditional crop insurance, they relied on it to protect against adverse weather and prices. Traditional crop of insurance is usually not privately provided partly because of adverse selection, which occurs when some farmers do not voluntarily participate – only those likely to claim benefits participate in private crop insurance. Requiring all farmers to participate eliminates this problem, but at a cost to society – it effectively subsidizes farmers and thus must be provided by government. Even so, such a program cannot eliminate the problem of moral hazard, which happens because farmers take no steps to reduce their exposure to risk. Farmers no longer diversify their operations, but specialize in only one activity (crop or livestock). Farmers' decisions are contrary to the desires of the insurer, with farmers taking on risks they would otherwise avoid.

Financial weather derivatives and weather-indexed insurance contracts are alternative instruments that can be used to hedge production risks related to weather outcomes. Payoffs or payouts depend on a weather index that has been carefully chosen to represent the weather conditions against which protection is being sought (Jewson et al. 2005). The problems of moral hazard and adverse selection disappear since the value of the weather index does not depend on the individual actions of market participants. Although the two hedging methods are essentially similar, there exist mature exchange markets for financial weather derivatives while weather indexed insurance relies solely on over-the-counter (OTC) contracts. Another difference is that, with financial weather derivatives, it may be necessary to perform frequent revaluations of derivative positions (known as market-to-risk or market-to-model), but this is usually not necessary for insurance. In this study, the focus is on financial weather derivatives – their construction and hedging efficiency.

China is the second largest maize producing country in the world after the United States (FAO 2010), with corn production in Northeastern China (Heilongjiang, Jilin and Liaoning provinces) alone accounting for 30.9% of total corn production in 2010 (China Statistical Yearbook 2011). Crop yields in the region are highly dependent on growing season weather conditions (Chen et al. 2011). Weather indexed insurance was introduced into China in 2008 (Liu et al. 2010); therefore, because corn production in Northeastern China is impacted by weather, such financial weather products could be used by farmers to mitigate weather risk. The objective of this paper is to investigate the potential weather risks and the efficiency of employing weather derivatives with different strike levels to hedge weather risks in the main crop growing region of China.

Turvey and Kong (2009) were the first to consider this issue in China. They found that there was significant interest by farmers in precipitation insurance in western China, where there was considerable risk of excessive rainfall following drought. Similarly, Liu et al. (2010) surveyed households in the central province of Anhui, where drought and flood pose major risks to crops. Farmers expressed a great deal of interest in weather index insurance to protect against these risks. As a result, it is worthwhile studying weather index derivatives and evaluating the efficiency of applying weather index contracts with different strike values to hedge weather risks for crop production.

The rest of this study is structured as follows. We begin in the next section with an overview of financial weather derivative product markets. Then we describe the study area and the data trends, followed by the methods employed for finding the potential weather variables that affect corn yields, pricing the weather derivatives, and evaluating the efficiency of the weather derivatives with different strike values. We end by discussing the results and making some concluding remarks.

Financial Weather Derivatives: Background

Trading in financial weather derivatives began in 1997, with an OTC contract based on heating degree days (HDD) struck between Koch Industrial and Enron Corporation (Brockett et al. 2007). Since then, trading grew rapidly as the Chicago Mercantile Exchange (CME) began to offer financial exchange-traded weather derivatives based on two weather indexes, HDD and cooling degree days (CDD) (Considine 2009). Financial weather derivatives consist of future (forward) contracts, options and swaps. A call option can be claimed when the value of the weather index is above a specified exercise or strike value, while a put option can be claimed when the value of the weather index is below a specified value. An American option may be exercised at any time prior to the expiration date or maturity, whereas a European option may be exercised only at maturity. The cost of acquiring an option is its premium. For call or put options, buyers take a long position, while sellers take a short position.

How does it work? A HDD is defined as a summation over a specified number of days of the degrees (^{o}C) that actual average daily temperature is below the threshold temperature of 18^{o}C. For example, if the realized average daily temperatures on two consecutive days are 14.5^{o}C and 16^{o}C, then the HDD measure equals 5.5^{o}C. Each HDD has a pre-defined monetary value so it is numbers of HDDs that occur in a specific period (usually one month) that are traded and not their price. Now assume that, if temperatures are too warm in winter, an energy company experiences lower than expected sales and thus reduced net revenues. It could protect against this outcome by purchasing a call option to sell HDDs in the future. If the actual number of HDDs lies above the contracted HDDs (it is warmer than usual), the company exercises the contract, earning a windfall to offset against the loss in revenues due to lower than anticipated sales. If

HDDs are lower, the option is not exercised and the company forfeits the premium, but it benefits from sales of heating services.

Weather derivatives can also be used to protect against crop losses associated with cold weather, extreme heat and/or too much rainfall. For example, a crop producer could insure against too little growing season warmth by participating in the exchanged-traded market for financial derivatives, purchasing a put option for CDDs (degree days that average daily temperatures during a period are above 18^{o}C) on the nearest exchange market, or an OTC put option based on growing degree days (GDD), which are defined with respect to a 5^{o}C or 10^{o}C threshold. Alternatively, if precipitation is a concern, an OTC option on cumulative rainfall (CR) can be purchased. A farmer could hedge against too few GDDs or too little CR by purchasing a put option that reduces the financial risk of reduced crop yield. If the realized weather outcomes are at or above the strike value, the farmer would not exercise the option and lose the premium paid for the option contract; in that case, yields are likely higher than expected, which would more than compensate for the premium.

Studies by Alaton et al. (2002), Brody et al. (2002), and Jewson et al. (2005) focused on methods for pricing weather derivative contracts, using burn analysis and parametric or non-parametric methods to specify a probability distribution of the weather index, or a stochastic process to model weather outcomes. Meanwhile, Turvey (2001), Stoppa and Hess (2003), and Lou and Sun (2013) were more concerned with the development of weather index instruments and their benefits for agricultural production, while Vedenov and Barnett (2004) and Musshoff et al. (2011) measured the efficiency of applying weather derivatives in this context. Specifically, they examined how well contracts reduced risk exposure. How do farmers determine when to enter the financial market?

Vedenov and Barnett (hereafter V&B, 2004) designed weather derivatives and evaluated the efficiency for crop producers by comparing their risk exposure with and without a financial weather derivative contract. They regressed crop yields for corn, cotton and soybeans in various crop districts in the United States on average monthly temperatures and precipitation, and cumulative growing season rainfall and CDDs over the period 1972 to 2001 using linear and quadratic functional forms. They set the strike levels to correspond to the average crop yields determined from the regression models, and estimated the limit values and tick sizes by minimising the difference between expected average revenues and those expected had the farmers purchased an option. V&B (2004) found that, by purchasing weather options or insurance based on weather indexes, a risk-averse farmer could, with some exceptions depending on the measure of variability employed, increase her utility.

In their study of wheat production in northern Germany, Musshoff et al. (2011) quantified the risk-reducing effect that could be achieved using precipitation options whose hedging effectiveness is controlled by the contract design (index, strike level and tick size). They compared outcomes with and without a financial weather derivative over the period 1993 to 2006 using a linear-limited (Leontief) production function. Strike level and tick size were selected using the estimated parameters.

Clearly, in order to indentify the parameters of optimal contracts, the weather variables must have a statistically significant and meaningful impact on crop yield – it must explain a significant amount of the variation in crop yields – before a weather index can be used to construct a financial instrument (Turvey 2001). The model can then be used to identify the strike level, and estimate the limit value and the tick size for an OTC contract. It is possible, however, that the estimation model generates a substantial error in identifying the strike level. For example, the goodness-of-fit statistics reported by V&B (2004) range from 35.5% to 86.6% depending on the crop and location, while those reported by Musshoff et al. (2011) varied only from 10% to 48%.

The current study builds on V&B (2004) and Musshoff et al. (2011) by delinking the crop yield regression model from the strike values used to price weather derivatives. Specifically, the regression model is only used to find the potential weather risks to crop production, rather than identify strike values corresponding to certain yields. By so doing, we avoid the risk from the unexplained part of the regression model, which accounted for 13%-64% in the V&B study and 52%-90% in Musshoff et al. Therefore, we identify the strike values for different values of the mean and standard deviation of the weather index. In a practical application, the current research provides technical support for the establishment and operation of a financial weather derivatives market.

Study Area and Data

The study area consists of three provinces in northeastern China – Heilongjiang, Jilin and Liaoning (Fig 1); this is part of China's main spring corn production area.[1] Researchers generally find that GDD has high-order nonlinear effects on crop yields (Sun and van Kooten 2013; Schlenker and Roberts 2008), but lack of sufficient observations on crop yields and weather may prevent the use of highly nonlinear models. Further, even if a highly nonlinear model can be estimated, it may not include the weather index of interest. V&B (2004) estimated the

[1] Heilongjiang has an area of 47.3 million hectares (M ha), and lies 121º11´-135º43´ E and 43º25´-53º33´ N, and 50-200 meters above sea level (asl); Jilin has an area of 18.7 M ha, and lies 121º38´ - 131º19´ E, 40º52´ - 46º18´ N, and 110-200 m asl; Liaoning has an areas of 14.8 H ha, and lies 118º53´ - 125º46´ E, 38º43´ - 43º26´ N, and 300-3300 m asl. Information is found at: http://www.hlj.gov.cn/zjlj/wzzk/ (Heilongjiang); http://www.jl.gov.cn/jlgk/dldm/dlwz/ (Jilin); and http://www.ln.gov.cn/zjln/zrgm/ (Liaoning).

relationship between crop yield and monthly or cumulative CDDs and/or precipitation during the growing season over 30 years of observations; Stoppa and Hess (2003) employed 23 years of data to estimate a relationship with crop yields and rainfall for Morocco; and Turvey (2001) simply employed cumulative growing season rainfall and heating days over 58 years. For financial weather derivatives, it is important to find a relationship between a measurable and simply understood weather index and crop yield. In the present study, the provincial weather and crop yield data cover the period 1978 to 2010, or 33 years.

We regress corn yields on seasonal GDD and CR using only linear and quadratic terms on the weather variables. GDDs in year *t* in province *j* are calculated by subtracting 10^0C from the average temperature for each day *d* in the growing-season (May to September) and summing:

(1) $GDD_{tj} = \sum_{d=1}^{n}\left(max\left\{T_{d,t,j} - 10, 0\right\}\right)$,

where GDD_{tj} is cumulative GDD in year *t* in province *j*, $T_{d,t,j}$ is the temperature on day *d* in year *t* in province *j*, and there are *n* days in the growing season (taken to be 153 for corn). Corn yields are provincial annual average corn yields per ha for each province.

A summary of the data is provided in Table 1, while Shapiro-Wilkes W-tests for a normal distribution are provided in Table 2 corn yields, GDD and CR. For a 0.01 level of significance, results indicate that each of these random variables is normally distributed. Trends in each of the variables in each province over the period 1978 to 2010 are indicated in Figures 2, 3 and 4, respectively. There is a clear upward trend in corn yields and GDD, but no obvious trend in cumulative rainfall. Therefore, when employing Augmented Dickey-Fuller t-statistics to test for unit roots, an explicit time trend is assumed for yields and GDD, but CR is tested without a trend. The Dickey-Fuller tests with p-values are provided in Table 3; at a 0.05 level of significance, the null hypothesis of no unit root cannot be rejected (p-value = 0.3482) only for corn yields in

Heilongjiang province. Therefore, corn yields for that province are differenced, while those for Jilin and Liaoning provinces, and the GDD data for all three provinces are de-trended. The tests reported in Table 3 also indicate that the CR data do not need to be differenced or de-trended. The equations for differencing and de-trending the data are:

(2) $y_{dif} = y_t - y_{t-1}$ and

(3) $y_{det} = y_t - \hat{y}_t$,

where y_{dif} is the yield difference between year t and $t-1$, and $\hat{y}_t$ is the estimated yield determined by $\hat{y}_t = \alpha_0 + \alpha_1 t$, where α_0 and α_1 are estimated parameters.

Empirical Model

The efficacy of weather derivatives on rainfall or heat depends on a number of factors, the most important of which is the identification of specific risks (Turvey 2001). The relationship between crop yields and GDD and CR is specified as:

(4) $y_{jt} = \beta_0 + \beta_1 GDD_{jt} + \beta_2 GDD_{jt}^2 + \beta_3 CR_{jt} + \beta_4 CR_{jt}^2 + \beta_5 t_{jt} + \varepsilon_{jt}$,

where y_{jt} is the corn yield in province j in year t, β_i (i=1, …, 5) are parameters to be estimated, and $\varepsilon_{jt} \sim N(0, \sigma^2)$ is the error structure. The quadratic terms are used to capture turning points beyond which the weather index is too high. Robust regression is employed as it can overcome the inefficiencies caused by autocorrelation in time series.

Payoffs and Premiums of Weather Derivatives

Farmers can purchase a put option in the event that the weather index (either the GDD or CR index) is too low, or a call option in the event that it is too high. The payoff functions for long put and call contracts (from standpoint of buyers) are given by (Jewson et al. 2005):

$$(5)\ p(x)_{put} = \begin{cases} D(K_1 - x), x \leq K_1 \\ 0, x > K_1 \end{cases},$$

$$(6)\ p(x)_{call} = \begin{cases} 0, x < K_2 \\ D(x - K_2), x \geq K_2 \end{cases},$$

where $p(x)$ is the payoff; D is the tick size (dollar value per unit of the weather index); K_1 and K_2 are the strike (trigger) values for the put and call options, respectively; and x is the weather index. For long put and call contracts, these are the payoffs against low and high values of the weather index, respectively.

The premium (price of an option) is calculated from the expected payoff as follows (Alton et al. 2002):

$$(7)\ c = e^{-r(t_n - t)} E_p,$$

where c is the premium that the hedgers (buyers) need to pay for a contract, r is a risk-free periodic market interest rate, t is the date the contract is issued, t_n is the date the contract is claimed or the expiration date, and E_p is the expected payoff. The seller of the option would expect a reward for taking on the risk, and hence the premium would be higher than the expected payoff by a risk loading (Jewson et al. 2005). In this study, the risk loading is set as 20% of the expected payoff of the contract.

Assuming that the weather index follows a normal distribution, the expected payoff is:

$$(8)\ E_p = \int_{-\infty}^{\infty} p(x)\, f(x) dx,$$

where $f(x)$ is the probability distribution function (PDF) of the weather index. Upon transforming the weather index into a standard normal distribution, the payoff function becomes:

$$(9)\ E_p = \frac{1}{\sigma} \int_{-\infty}^{\infty} p(x)\, q(x') dx,$$

where σ is the standard deviation of the weather index, and $q(x')$ is the PDF of a standard normal distribution, $x' = \frac{x-\mu}{\sigma}, f(x) = \frac{1}{\sigma} q(x')$.

Inserting payoff functions (5) and (6) for the put and call contracts into (9) gives the closed-form functions for uncapped put and call options (Jewson et al. 2005). For a put option,

(10) $E_{p_{put}} = \frac{1}{\sigma} \int_{-\infty}^{K_1} D(K_1 - x)\, q(x') dx$,

which can be rewritten as

(11) $E_{p_{put}} = D\sigma q_{K_1'} + DQ_{K_1'}(K_1 - \mu)$,

For a call option,

(12) $E_{p_{call}} = \frac{1}{\sigma} \int_{K_2}^{\infty} D(x - K_2)\, q(x') dx = D\sigma q_{K_2'} + D(\mu - K_2)\left(1 - Q_{K_2'}\right)$,

where μ is the mean value of the weather index; K_1' and K_2' are the standardized normal lower and upper strike values, respectively; $q_{K_1'}$ and $q_{K_2'}$ are the associated values of the PDFs for K_1' and K_2'; $Q_{K1'}$ and $Q_{K2'}$ are the cumulative distribution functions (CDF) for K_1' and K_2'; and x is the weather index.

Following Considine (2009), let $K_1' = \frac{K_1 - \mu}{\sigma} = -m$, and $K_2' = \frac{K_2 - \mu}{\sigma} = m$ where m = {0.2, 0.4, …, 2.0}. Then equations (11) and (12) can be written as:

(13) $E_{p_{put}} = D\sigma(q_{-m} - mQ_{-m})$

(14) $E_{p_{\text{call}}} = D\sigma(q_m - m + mQ_m)$

Efficiency of Weather Derivatives

V&B (2004) analyzed the risk-reducing performance of weather derivatives by comparing producers' revenues with and without a contract. Producers' respective profits without and with weather derivatives are given as follows:

(15) $R_0 = P \times y_t$, and

(16) $R_1 = P \times y_t + p_t - c_t$,

where R_0 is a producer's revenue without a weather derivative contract and R_1 is the revenue with a weather contract; P is crop price per unit; y_t is corn yield in year t; and p_t and c_t are the payoff and the premium, respectively, of a contract in year t. As before, the expected yield is $\hat{y}_t$, and let the differences between $\hat{R}_t$ (the expected revenue) and R_0, and between $\hat{R}_t$ and R_1, be the producer's profit risk without and with a weather derivative contract, respectively.

Three efficiency measures are used by V&B (2004) to evaluate weather derivative contracts. Since these measures produce very similar results, we only analyze the mean root square loss (MRSL), which is defined as:

(17) $$MRSL_0 = \sqrt{\frac{1}{T}\sum_{t=1}^{T}[max(P\hat{y_t} - R_0, 0)]^2}$$

(18) $$MRSL_1 = \sqrt{\frac{1}{T}\sum_{t=1}^{T}[max(P\hat{y_t} - R_1, 0)]^2} = \sqrt{\frac{1}{T}\sum_{t=1}^{T}[max(P\hat{y_t} - (R_0 + p_t - c_t), 0)]^2} ,$$

where $MRSL_0$ and $MRSL_1$ are the *MRSL* without and with a weather contract. A smaller *MRSL* implies weaker exposure to risk.

Results

The estimated coefficients on the relationship between corn yields and the climate variables used to establish our weather index variables are provided in Table 4. For Heilongjiang province, none of the coefficients on the climate variables are significant, while for Jilin the coefficient on the linear term for CR is statistically significant, and for Liaoning the coefficients on the linear and quadratic terms for CR are statistically significant. This indicates that rainfall is an important index for both Jilin and Liaoning, with too much rainfall in Liaoning province harmful for corn production. Moreover, R^2 (=0.346) for Liaoning province is much higher than that for Jilin (0.209), which means that the weather variables better explain yield variation in Liaoning than Jilin province. Based on the regression results in Table 4, we construct rainfall index derivatives for hedging low and high rainfall only for Jilin and Liaoning provinces.

The premiums per contract for Jilin and Liaoning at different strike levels are provided in Tables 5 and 6, respectively, while the contract structure is listed in Table 7. It is clear that the premiums are decreasing as the strike values diverge from the mean value. $MRSL_0$ for Jilin province is 179.11, and $MRSL_0$ for Jilin is 168.00. In Table 6, the $MRSL_1$ for put and call options at different strike levels for Jilin are all higher than $MRSL_0$ (179.11) for that province; this implies that the risk exposure is stronger with a contract than without a contract. Therefore, it is inefficient for farmers to employ financial cumulative rainfall derivatives in this region. For Liaoning province, on the other hand, the $MRSL_1$ for put and call options at different strike levels are all lower than $MRSL_0$ (168.00), which indicates that the risk exposure is less with a contract than that without a contract. Therefore, it is likely efficient to purchase financial CR derivatives in this province. A comparison of the R^2 values for the Jilin (20.9%) and Liaoning (34.6%) regression models indicates that, when the weather variables explain only a small part of the variation in yields, it is inefficient for farmers to hedge weather risks by applying weather derivatives, and vice versa.

Conclusions

We find that it is efficient to employ financial weather derivatives to hedge risk only when the weather index explains a large degree of yield variation. For instance, when the weather variable explains 34.6% of the variation in yield, a hedge can offset the revenue loss caused by the corresponding weather risk; however, when it explains only 20.9% of yield variation, it is not efficient for the hedger to buy the corresponding weather derivatives.

Furthermore, when the weather variable explains a large enough component of the yield variation, then, as the selected threshold is lowered for put options or raised for call options, the cost of the contract is reduced as the risk exposure declines. Specifically, it is more effective to hedge the corresponding weather risk with a weather derivative contract with a strike value that is farther away from the mean value of the corresponding weather variable. In a practical application, our research provides technical support for the establishment and operation of a financial weather derivatives market. However, future research needs to examine how the premiums and payoffs change with the change in limit values – that is, capped contracts with varying limits.

For the provinces of Jilin and Liaoning, cumulative rainfall during the growing season is an important weather index that has a statistically significant effect on corn yields, although the effect is more pronounced in Liaoning than Jilin province. Therefore, it is only efficient to write and trade CR-based over-the-counter weather derivatives in Liaoning province. However, there might remain substantial basis risk between the point of measurement and the point of risk (Turvey 2001), because the weather data used to construct weather contracts does not reflect the weather conditions at the corresponding farm. This problem can be remedied to some extent by triangulating weather data to a specific point, providing farmers with the flexibility to choose and combine weather stations, or, more troublesome, locate a weather monitoring facility at the farm.

Although pricing weather derivatives over a large area may be foolhardy, the purpose of this study was to demonstrate how one might apply appropriate methods for constructing and implementing weather derivatives most efficiently. In practical applications, weather contracts can be constructed for each weather station located in a region, farmers could choose the contracts for certain weather stations based on their location relative to the farm. Farmers could then choose hedging strategies on the basis of their knowledge of farm management methods (including agronomic practices) and past experience regarding the types of weather risks that they face (Turvey and Kong 2009; Liu et al. 2010).

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Table 1: Data Description, 33 Years of Observations

Variable/Province	Mean	Std. Dev.	Min	Max
Corn Yields (*kg/ha*)				
Heilongjiang	4080.1	938.03	2405.8	5836.5
Jilin	5710.3	1285.79	3014.5	7949.0
Liaoning	5391.3	920.59	3691.7	6842.9
Growing degree days (^{o}C)				
Heilongjiang	1008.7	80.07	867.6	1201.9
Jilin	1375.8	86.94	1243.0	1599.1
Liaoning	1687.0	90.76	1536.2	1914.6
Cumulative rainfall (*mm*)				
Heilongjiang	433.0	63.31	315.4	556.4
Jilin	478.9	73.66	372.5	657.2
Liaoning	523.5	115.65	339.5	818.4

Table 2: Shapiro-Wilkes W-Tests for Normal Distributions, n=33

Variable/Province	W	V	z	Prob>z
Crop yields				
Heilongjiang	0.94572	1.853	1.283	0.09978
Jilin	0.92180	2.67	2.042	0.02056
Liaoning	0.94962	1.72	1.128	0.12970
Growing degree days				
Heilongjiang	0.97386	0.892	-0.237	0.59354
Jilin	0.96599	1.161	0.310	0.37815
Liaoning	0.97537	0.841	-0.361	0.64091
Cumulative rainfall				
Heilongjiang	0.97876	0.725	-0.669	0.74822
Jilin	0.92995	2.392	1.814	0.03487
Liaoning	0.94523	1.87	1.302	0.09654

Table 3: Augmented Dickey-Fuller(ADF) t-statistics for Unit Root tests, n=33

	Heilongjiang			Jilin			Liaoning		
	Yield	GDD	CR	Yield	GDD	CR	Yield	GDD	CR
p value	0.3482	0.0000	0.0003	0.0155	0.0001	0.0001	0.00	0.002	0.0002

Table 4: Regressions of Corn Yields on Weather Variables [a]

Province→	Heilongjiang		Jilin		Liaoning	
Item	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
GDD	-0.04	2.108	-3.43	2.976	-0.62	2.096
GDD^2	-0.01	0.026	-0.02	0.026	-0.02	0.020
CR	24.91	23.765	61.23*	35.301	29.56***	10.646
CR^2	-0.03	0.027	-0.06	0.035	-0.03***	0.009
Intercept	-5731.60	5064.177	-15588.86*	8738.905	-7903.95**	2984.064
d. of f.	27		27		27	
R^2	0.094		0.209		0.346	

[a] *, ** and *** refer to the 0.1, 0.05 and 0.01 levels of statistical significance, respectively.

Table 5: Strike Levels and Premiums for Put and Call Options for Jilin Province[a]

Put			Call		
K_1	K_1 (mm)	Premium ($/ Contract)	K_2	K_2 (mm)	Premium ($/ Contract)
μ-0.2σ	464.12	26.61	μ+0.2σ	493.58	26.61
μ-0.4σ	449.39	19.98	μ+0.4σ	508.31	19.98
μ-0.6σ	434.65	14.63	μ+0.6σ	523.05	14.63
μ-0.8σ	419.92	10.42	μ+0.8σ	537.78	10.42
μ-1.0σ	405.19	7.22	μ+1.0σ	552.51	7.22
μ-1.2σ	390.45	4.86	μ+1.2σ	567.24	4.86
μ-1.4σ	375.73	3.18	μ+1.4σ	581.97	3.18
μ-1.6σ	360.99	2.02	μ+1.6σ	596.71	2.02
μ-1.8σ	346.26	1.24	μ+1.8σ	611.44	1.24
μ-2.0σ	331.53	0.74	μ+2.0σ	626.17	0.74

[a] r=1.92% (risk free interest rate), T=1year (expire time), α=20% (risk loading), D=$1 (tick size); K refers to strike values; μ and σ refer to the mean and standard deviation of CR.

Table 6: Strike Levels and Premiums for Put and Call Options for Liaoning Province[a]

Put			Call		
K_1	K_1 (mm)	Premium ($/ Contract)	K_2	K_2 (mm)	Premium ($/ Contract)
μ-0.2σ	500.39	41.78	μ+0.2σ	546.65	41.78
μ-0.4σ	477.26	31.37	μ+0.4σ	569.78	31.37
μ-0.6σ	454.13	22.96	μ+0.6σ	592.91	22.96
μ-0.8σ	431.00	16.37	μ+0.8σ	616.04	16.37
μ-1.0σ	407.87	11.34	μ+1.0σ	639.17	11.34
μ-1.2σ	384.74	7.64	μ+1.2σ	662.30	7.64
μ-1.4σ	361.61	4.99	μ+1.4σ	685.43	4.99
μ-1.6σ	338.48	3.16	μ+1.6σ	708.56	3.16
μ-1.8σ	315.35	1.94	μ+1.8σ	731.69	1.94
μ-2.0σ	292.22	1.16	μ+2.0σ	754.82	1.16

[a] See footnote *a* in Table 4.

Table 7: Specification of CR options for Jilin and Liaoning Provinces

Items	Call Option	Put Option
Weather Index	CR	CR
Reference Station	Average value	Average value
Strike Level	See Tables 4 and 5	See Tables 4 and 5
Tick Size	\$ 1	\$ 1
Premium	See Tables 4 and 5	See Tables 4 and 5
Payoff	Max (K_1-CR, 0)	Max (CR-K_2, 0)
Issue Time	September 31, 2010	September 31, 2010
Maturity Time	September 31, 2011	September 31, 2011

Table 8: Mean Root Square Losses ($MRSL_1$) for Jilin and Liaoning Provinces[a]

	Jilin Province		Liaoning Province	
Strikes	put	call	put	call
μ+/-0.2σ	194.39	187.77	160.71	152.55
μ+/-0.4σ	193.77	187.28	158.13	149.42
μ+/-0.6σ	192.93	187.69	154.68	147.42
μ+/-0.8σ	191.09	188.43	151.17	146.41
μ+/-1.0σ	189.12	187.66	148.59	145.72
μ+/-1.2σ	187.68	187.21	146.81	145.10
μ+/-1.4σ	186.65	186.52	145.22	145.13
μ+/-1.6σ	185.94	185.87	144.12	144.12
μ+/-1.8σ	185.47	185.40	143.40	143.40
μ+/-2.0σ	185.16	185.09	142.93	142.93

[a] For the put options, the strikes are at μ–*m*σ; for the call options, the strikes are at μ+*m*σ; a price of $273.30/tonne in 2010 is used for all years (FAO 2010).

Figure 1: Study area indicating Heilongjiang, Jilin and Liaoning provinces, China
(Source: Data Sharing Infrastructure of Earth System Science from 1977–96)

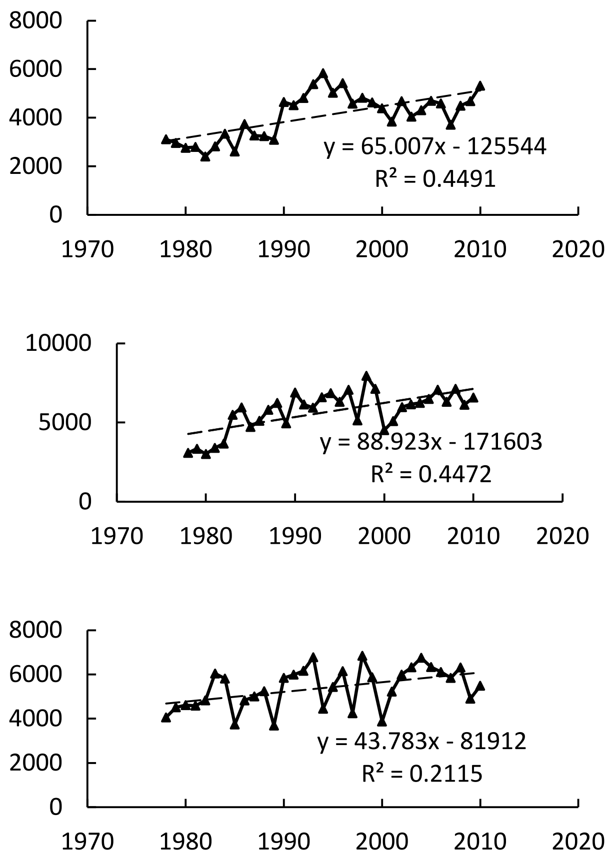

Figure 2: Trends in crop yields (kg/ha) for Heilongjiang (top panel), Jilin (middle panel) and Liaoning (bottom panel) provinces, 1978-2010

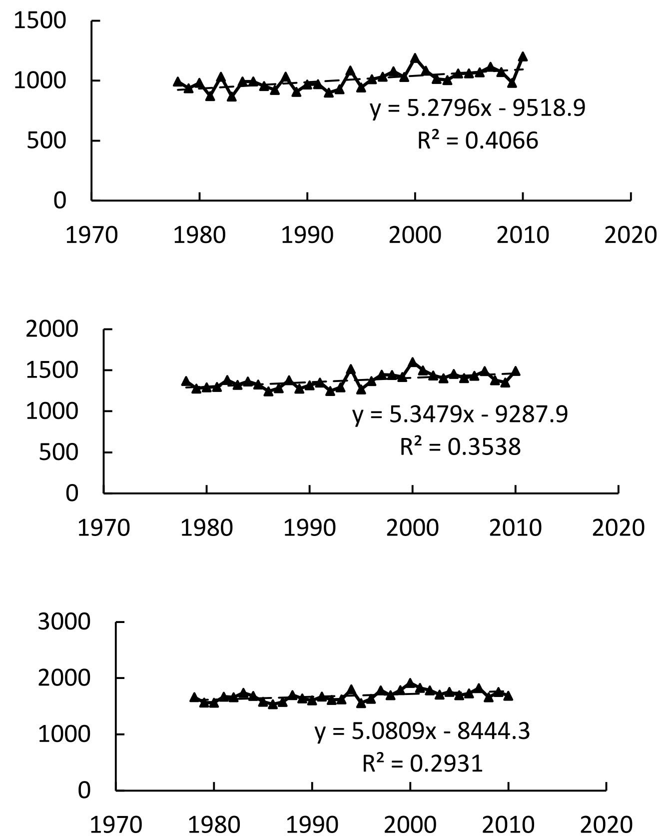

Figure 3: Trends in growing degree days (GDD; degrees Celcius) for Heilongjiang (top panel), Jilin (middle panel) and Liaoning (bottom panel) provinces, 1978-2010

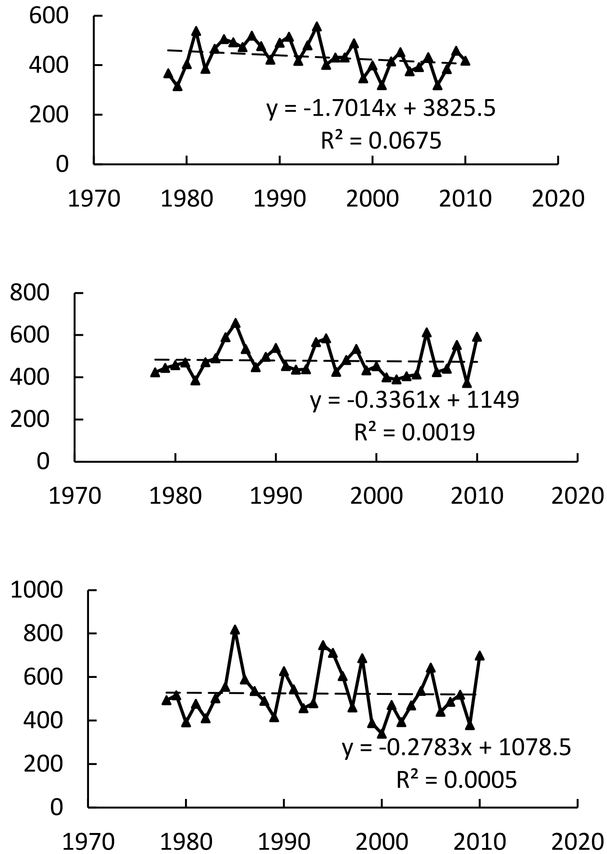

Figure 4: Trends in cumulative rainfall (CR; mm) for Heilongjiang (top panel), Jilin (middle panel) and Liaoning (bottom panel) provinces, 1978-2010