Vancouver, British Columbia, Canada
June 16 - 18, 2013
www.iarfic.org

Hosts:

watRISQ

中国精算研究院

Warren Centre for Actuarial Studies and Research
Hedging Weather Risk for Corn Production in Northeastern China: Efficiency of Weather Derivatives

Baojing Sun, Changhao Guo, and G. Cornelis van Kooten
Department of Economics
University of Victoria

The Second International Agricultural Risk, Finance, and Insurance Conference (IARFIC), June 16-18, 2013, Vancouver.
Abstract

Is it efficient to apply financial weather derivatives to hedge weather risks?

How does the potential weather index impact the efficiency of applying the financial derivative?

Results show that cumulative rainfall (CR) is an important factor for corn production in the study region.

Under some circumstances, it is efficient to use a financial weather derivatives to hedge risk, but not in all cases.
Outline

- Introduction
- Study area and data
- Weather effects on corn yields
- Payoff and premium of weather derivatives
- Efficiency of weather derivatives
- Results
- Conclusions
Introduction

Financial weather derivatives and weather-indexed insurance contracts are alternative instruments that can be used to hedge production risks related to weather outcomes.

Problems with traditional crop insurance: (1) moral hazard and (2) adverse selection.

Financial weather derivatives avoid these problems since the value of the weather index does not depend on the individual actions or numbers of market participants.
Little research measures the efficiency of applying weather derivatives in crop production situations. Exceptions are:

Vedenov and Barnett (2004) set strike levels to correspond to the average crop yields determined from regression models.

(Musshoff et al. (2011) estimated parameters (strike levels, etc.) from a linear-limited (Leontief) production function.)
The estimation model used to identify the strike level may generate a substantial error.

For example, the goodness-of-fit statistics reported by V&B (2004) ranges from 35.5\% to 86.6\%.

Those reported by Musshoff et al. (2011) varied from 10\% to 48\%.
To address this problem, in the current research, the regression model is used only to find the potential weather risks to crop production, rather than identify strike values corresponding to certain yields.

To investigate the effects of changes in strike values, we identify the different values of the mean and standard deviation of the weather index as the strike values.

We avoid the risk from the unexplained part of the regression model.
Study area and data

The study area consists of three provinces in northeastern China. This area accounted for about 31% of total corn production in China in 2010.
Methods

Weather effects on corn yields

Regress corn yields on seasonal growing degree days (GDD) and cumulative rainfall (CR) using linear and quadratic terms on the weather variables.

The quadratic term is used to capture the effects of too much heat or water.

GDDs are calculated by subtracting 10°C from the average temperature for each day in the growing-season (May to September) and summing.

CRs are cumulative rainfall over the growing season for corn.

Both of GDDs and CRs are normally distributed.

(Note: We cannot use Shlenker & Roberts approach due to lack of data on weather variables.)
Payoffs

A call option can be claimed when the value of the weather index is above a specified strike value, while a put option can be claimed when the value of the weather index is below a specified value (Jewson et al. 2005).

\[
p(x)_{\text{put}} = \begin{cases} D(K_1 - x), & x \leq K_1 \\ 0, & x > K_1 \end{cases}
\]

\[
p(x)_{\text{call}} = \begin{cases} 0, & x < K_2 \\ D(x - K_2), & x \geq K_2 \end{cases}
\]

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 values, respectively; and \( x \) is the weather index.
Premiums

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

\[ c = \exp (-r(t_n - t)) E_p \]

where \( c \) is the premium, \( r \) 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, and \( E_p \) is the expected payoff.
Expected payoff

The expected payoff is (Jewson et al. 2005):

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

where \( f(x) \) is the probability density function (PDF) of the weather index (normal distribution in this study), and \( p(x) \) is the payoff.
Efficiency of Weather Derivatives

Revenue without and with a weather derivative contract:

\[ R_0 = P \times y_t \quad \text{and} \quad R_1 = P \times y_t + p_t - c_t \]

where \( R_0 \) is a producer’s revenue without contract and \( R_1 \) is the revenue with a contract; \( P \) is crop price per unit; \( y_t \) is corn yield; and \( p_t \) and \( c_t \) are the payoff and the premium.
We employ mean root square loss (MRSL) to measure the efficiency of applying using weather derivatives

\[
MRSL_0 = \sqrt{\frac{1}{T} \sum_{t=1}^{T} \left[ \max(Py'_t - R_0, 0) \right]^2}
\]

\[
MRSL_1 = \sqrt{\frac{1}{T} \sum_{t=1}^{T} \left[ \max(Py'_t - R_1, 0) \right]^2}
\]

where \( MRSL_0 \) and \( MRSL_1 \) are the MRSL without and with a weather contract; \( y'_t \) is the expected yield.

A smaller MRSL implies weaker exposure to risk.
# Results

<table>
<thead>
<tr>
<th>Province</th>
<th>Heilongjiang</th>
<th>Jilin</th>
<th>Liaoning</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDD</td>
<td>-0.04</td>
<td>-3.43</td>
<td>-0.62</td>
</tr>
<tr>
<td>GDD²</td>
<td>-0.01</td>
<td>-0.02</td>
<td>-0.02</td>
</tr>
<tr>
<td>CR</td>
<td>24.91</td>
<td>61.23*</td>
<td>29.56***</td>
</tr>
<tr>
<td>CR²</td>
<td>-0.03</td>
<td>-0.06</td>
<td>-0.03***</td>
</tr>
<tr>
<td>Intercept</td>
<td>-5731.60</td>
<td>-15588.86*</td>
<td>-7903.95**</td>
</tr>
<tr>
<td>R²</td>
<td>0.094</td>
<td>0.209</td>
<td>0.346</td>
</tr>
</tbody>
</table>

Table 1 Regressions of Corn Yields on Weather Variables by Province
From Table 1:
Heilongjiang province: None of the coefficients on the climate variables are significant.

Jilin province: The coefficient on the linear term for CR is statistically significant.

Liaoning province: The coefficients on the linear and quadratic terms for CR are statistically significant.
In terms of financial weather derivatives, rainfall might be an important potential weather index for both Jilin and Liaoning provinces.

$R^2 (=0.346)$ for Liaoning province is much higher than that for Jilin (=0.209).

The weather variables better explain yield variation in Liaoning than Jilin province.

We construct rainfall index derivatives for Jilin and Liaoning provinces.
Table 2 Strike Levels and Premiums for Put and Call Options for Jilin Province

<table>
<thead>
<tr>
<th>Put</th>
<th>Call</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>K_1</strong>&lt;br&gt;(mm)</td>
<td><strong>K_1</strong>&lt;br&gt;(mm)</td>
</tr>
<tr>
<td>µ-0.2σ</td>
<td>464.12</td>
</tr>
<tr>
<td>µ-0.4σ</td>
<td>449.39</td>
</tr>
<tr>
<td>µ-0.6σ</td>
<td>434.65</td>
</tr>
<tr>
<td>µ-0.8σ</td>
<td>419.92</td>
</tr>
<tr>
<td>µ-1.0σ</td>
<td>405.19</td>
</tr>
<tr>
<td>µ-1.2σ</td>
<td>390.45</td>
</tr>
<tr>
<td>µ-1.4σ</td>
<td>375.73</td>
</tr>
<tr>
<td>µ-1.6σ</td>
<td>360.99</td>
</tr>
<tr>
<td>µ-1.8σ</td>
<td>346.26</td>
</tr>
<tr>
<td>µ-2.0σ</td>
<td>331.53</td>
</tr>
</tbody>
</table>
Table 3 Mean Root Square Losses (MRSL₁) for Jilin and Liaoning Provinces (MRSL₀ for Jilin province is 179.11, and MRSL₀ for Jilin is 168.00.)

<table>
<thead>
<tr>
<th></th>
<th>Jilin</th>
<th></th>
<th>Liaoning</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>put</td>
<td>call</td>
<td>put</td>
</tr>
<tr>
<td>K₁</td>
<td>µ-0.2σ</td>
<td>194.39</td>
<td>187.77</td>
</tr>
<tr>
<td>µ-0.4σ</td>
<td>193.77</td>
<td>187.28</td>
<td>158.13</td>
</tr>
<tr>
<td>µ-0.6σ</td>
<td>192.93</td>
<td>187.69</td>
<td>154.68</td>
</tr>
<tr>
<td>µ-0.8σ</td>
<td>191.09</td>
<td>188.43</td>
<td>151.17</td>
</tr>
<tr>
<td>µ-1.0σ</td>
<td>189.12</td>
<td>187.66</td>
<td>148.59</td>
</tr>
<tr>
<td>µ-1.2σ</td>
<td>187.68</td>
<td>187.21</td>
<td>146.81</td>
</tr>
<tr>
<td>µ-1.4σ</td>
<td>186.65</td>
<td>186.52</td>
<td>145.22</td>
</tr>
<tr>
<td>µ-1.6σ</td>
<td>185.94</td>
<td>185.87</td>
<td>144.12</td>
</tr>
<tr>
<td>µ-1.8σ</td>
<td>185.47</td>
<td>185.40</td>
<td>143.40</td>
</tr>
<tr>
<td>µ-2.0σ</td>
<td>185.16</td>
<td>185.09</td>
<td>142.93</td>
</tr>
</tbody>
</table>
From Table 2, it is clear that the premiums are decreasing as the strike values diverge from the mean value.

From Table 3, the MRSL$_1$ for put and call options at different strike levels for Jilin exceed MRSL$_0$ (179.11).

The risk exposure is greater with a contract than without a contract.

It is inefficient for farmers to employ financial cumulative rainfall derivatives in Jilin province.
For Liaoning province, the MRSL₁ for put and call options at different strike levels are smaller than the MRSL₀(168.00).

The risk exposure is less with a weather derivative contract than that without a contract.

It is likely efficient to purchase financial Cumulative Rainfall derivatives in this province.
Conclusions

When weather variables explain a significant amount of the variation in yields, it is efficient for farmers to purchase weather derivatives, and vice versa.

When it is efficient to apply derivative contracts then, as the selected threshold is lowered for put options or raised for call options, the hedging efficiency increases.

In other words, it is efficient to hedge larger variances in the weather index than smaller ones by choosing thresholds that are farther away from the mean value of the index.
• Thank you for your attention!

• Contact information: Baojing Sun, baojings@uvic.ca.