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Financial weather derivatives for corn production in Northern China: A comparison of pricing methods

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ABSTRACT

The focus in this study is on the pricing of financial derivatives for hedging weather risks in crop production. Employing data from an earlier study, we compare different methods for pricing weather derivative options based on growing degree days (GDDs). We employ average daily temperatures to derive GDDs using three approaches: (1) An econometric approach with a sine function; (2) Monte Carlo simulation with a sine function and three methods to estimate the mean-reversion parameter; and (3) a historic approach (burn analysis) based on a 10-year moving average of GDDs. Results indicate that the historical average method provides the best fit, followed by the stochastic process with a high mean reversion speed, and, finally, the approach using the econometrically estimated sine function. Depending on the method used, premiums for weather derivative options vary from $21.27 to $24.39 per GDD index contract.

1. Introduction

Financial weather derivatives and weather-indexed insurance are alternative private-sector instruments that can be used to hedge production risks related to weather outcomes. Payoffs depend on a weather index that has been carefully chosen to represent the weather conditions against which protection is being sought. The problems of moral hazard and adverse selection that exist in traditional crop insurance disappear since the value of the weather index does not depend on the individual actions of market participants. Although the two hedging methods – weather derivatives and weather indexed insurance – are essentially similar, there exist mature exchange markets for some financial weather derivatives while weather-indexed insurance relies solely on over-the-counter (OTC) contracts. Another important difference is that financial weather derivatives not only provide economic agents impacted by weather (e.g., farmers, energy firms) with a tool for hedging weather risks, but also provide an investment instrument that participants in financial markets can purchase for diversifying their portfolios.

Trading in financial weather derivatives began in 1997, with an OTC contract based on heating degree days (HDDs) struck between Koch Industrial and Enron Corporation (Brockett et al., 2007). Since then, trading has grown rapidly as the Chicago Mercantile Exchange (CME) began offering financial exchange-traded weather derivatives based on two weather indexes, HDDs and CDDs (cooling degree days) (Considine, 2009). A party wishing to hedge against adverse weather can purchase an option on one of these two weather indexes: 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. 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.

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Weather derivatives can be used to protect against crop losses associated with cold weather, extreme heat, and/or too much or too little precipitation, although financial rainfall products are generally traded OTC. For example, a crop producer could insure against too little growing season warmth by holding a put option based on growing degree days (GDDs), which measure the dependence of crops on warmth and are defined with respect to a 5 °C or 10 °C threshold. Alternatively, if precipitation is a concern, an 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 low crop yield. If the realized weather outcome is 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. If the weather outcome is below the strike value, the farmer receives a payout to compensate for the lower yields and reduced revenue from the adverse weather.

In this paper, we examine potential pricing of weather derivatives in China, which is the second largest maize producing country in the world after the United States (FAO, 2010). Crop yields in northern China (mainly areas in Inner Mongolia and Shaanxi province) are highly dependent on growing season weather conditions, especially heat conditions during the growing season (Sun and van Kooten, 2014). Therefore, farmers could use a GDD-based financial weather product to mitigate weather risk.

A number of studies have focused on methods for pricing weather derivative contracts, including Alaton et al. (2002), Brody et al. (2002), Campbell and Diebold (2005), and Jewson et al. (2005). In these studies, burn analysis and parametric or non-parametric methods were used to specify a probability distribution of the weather index, or, alternatively, a stochastic process was employed to model weather outcomes. Not surprisingly, most studies of weather derivatives focused on market-based HDD or CDD indexes in the energy sector (Goncu, 2011; Huang et al., 2008; Schiller et al., 2012). In agriculture, where financial weather derivatives have not been adopted on the same scale as in the energy sector, studies have looked at rainfall or heat index-based weather derivatives, using historical data to construct such indexes (Musshoff et al., 2011; Stoppa and Hess, 2003; Sun and Lou, 2013; Turvey, 2001; Vedenov and Barnett, 2004).

The main objective of the current study is to examine three pricing methods for weather derivatives and compare them on the basis of historic weather conditions and weather predictions. The methods we employ to price weather derivatives based on GDDs are a weather index distribution method using historic averages (burn analysis), an estimated non-stochastic sine function, and a stochastic process with Monte Carlo simulation (and three approaches for estimating the mean-reverting parameter). Our application is to a major corn growing region in northern China, using historic weather data to estimate the required relationships; to do so, we rely on information from an earlier study on weather effects on corn yields in northern China (Sun and van Kooten, 2014).

The study is structured as follows. We begin in the next section with a discussion of the development of daily average temperatures, followed by the stochastic method for simulating daily average temperatures and description of a weather index distribution method to price weather derivatives. We end by discussing and analyzing the results, and making some concluding remarks.

2. Data and methods

2.1. Data description

Weather data are from the China Meteorological Data Sharing System. A plot of daily average temperatures for the period 2001 to 2011 at Etuokeqi in the Inner Mongolia Autonomous Region is provided in Fig. 1. This 11-year period includes two leap years and has 4017 observations; the daily average temperature over this period is 8.0 °C, with a standard deviation of 11.99 °C. The minimum and maximum temperatures are −22.4 °C and +29.9 °C, respectively, while daily average temperatures range from −15 °C in winter to 25 °C in summer. The figure illustrates the seasonality in average daily temperature movements, indicating in particular its similarity to a sine function.

Growing degree days are a measure of the heat to which crops are exposed during the growing season. In an earlier study, Sun and van Kooten (2014) show that corn yields are negatively impacted when growing season GDDs are too low or high, with GDD defined as: $GDD = \sum_{d=1}^{D} \text{Max}(0, T_d - 10)$, where D (=153) refers to the number of days in the growing season (May to September) and T_d is the average temperature on day d. For the 11 years in our sample, the average growing-season GDDs is 1449.78 °C with a standard deviation of 78.97 °C, and minimum and maximum values of 1294.1 °C and 1584.4 °C, respectively. A Shapiro–Wilk test for normality (W-statistic = 0.9683) cannot reject the null hypothesis that GDDs are normally distributed ($z = -1.121$, p = 0.869).

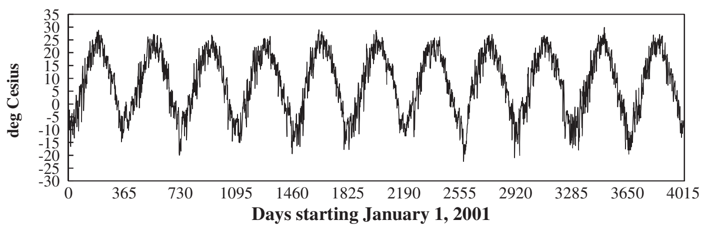

Fig. 1. Daily average temperatures, 2001 through 2011, Etuokeqi, Inner Mongolia (107° 59′ E, 39° 6′ N).