WEATHER DERIVATIVES AND SPECIFIC EVENT RISK

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Paper presented for presentation at the 1999 Annual Meeting of the AAEA
Nashville Tennessee
August 1999

Abstract

This paper investigates the relationship between weather events and agricultural risks. Specific event risks are defined by outcomes related to a specific event such as low temperature and rainfall. Using Ontario data this paper describes specific events and shows how these specific events can be insured using weather derivatives and insurance.

Key words: Heat insurance, rainfall insurance, weather derivatives, weather options, crop insurance, agricultural risk

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The role of weather in agricultural insurance is not new, but an emerging market for weather based insurance and derivative product is. In the U.S.A. companies such as World Wide Weather Insurance Inc., American Agrisurance Inc. and Natsource (a New York City brokerage) all offer weather risk products, and in Canada Royal Bank Dominion Securities Inc are now brokering weather specific derivative products. Applications are wide spread among natural gas, oil, and electricity sectors, but more and more such products are being used for agriculture insurance purposes. Weather derivatives differ from multiple peril crop insurance in that they pay out on the cause or source of risk rather than the effect and no proof of actual crop damages are required.

The main attraction with weather derivatives is that they provide a natural hedge against production risk rather than price risk. Rainfall and heat extremes are probably perils that contribute most to systematic risk across farms. Indeed, the U.S.A. Group Revenue Protection (GRP) policies are specifically designed to insure such risks (Miranda, Miranda and Glauber, Turvey and Islam). In this context one can imagine a crop insurer being short in area-yield insurance while reinsuring with a long position in the weather derivative which best describes systematic risk.

The weather derivative, whether brokered as an insurance contract or as an OTC traded option is described by some very specific language which identifies 3 main criteria: 1) the insured event, 2) the duration of the contract and 3) the location at which the event is measured.

The types of contracts used to insure weather events are varied, but in general there are two different types. First, there are multiple event contracts. An agribusiness firm may want to insure against multiple events of daily high temperature exceeding 90^{o}F for 4 days straight in order to compensate for yield and/or quality loss. Such a contract may allow for multiple events and will usually provide a fixed payoff per event.

Second, are straight forward derivative products based upon such notions as cooling degree days above 65^{o}F (an indication of electricity demand for air conditioning), heating degree days below 65^{o}F (an indication of electricity, oil, and gas demand required for heating), and growing degree days or crop heat units (an indication of maximum crop yield potential, or death loss in a poultry barn).

There are empirical issues related to weather insurance which I have dealt with elsewhere (Turvey 1999a,b). The most important issue is that because there is no forward market weather index, there is no mechanism that would allow brokers, traders, and/or insurers to price such derivatives on an ongoing and transparent basis, and this can impact liquidity in the market. Currently, the common approach is to use historical data and from this use traditional insurance 'burn-rate' methods to determine actuarial probabilities of the outcome. This convention limits trade. Counterparties must agree on a price prior to the opening contract date and are restricted by lack of data to efficiently price and trade the contract during the period in which it is active.

Defining Specific Event Risk

In order to fully understand the significance of weather insurance it is important to understand that the implied insured events make up less than 100% (in most cases) of crop yield variance. This contrasts with conventional multiple peril crop insurance which is defined by total variance. This section discusses the nature of these specific event risks.

The determination of crop yield distributions depends conditionally on specific events throughout the growing season defined by state variables such as weather or disease. These state variables take on any value at any moment in time and crop growth, yield quantity, and yield quality are conditioned upon these events. For purposes of insurability the conventional economic concern facing farmers, input suppliers, processors, marketers and creditors is in regards to final yield outcomes, which is in essence the sum effect of all specific events.

Specific event risk does not require an economic representation of yield growth and risk although there would be obvious advantages to correlating weather events to specific phenological events. A recent paper on biophysical modeling of corn by Kaufmann and Snell identifies such Phenological stages such as sowing to germination, seedling emergence, tassel initiation to silking, or grain filling. In this context, specific event risk refers to specific outcomes in state variables that occur at specific or unknown points along the growth curve. Examples of specific event risk include 2-week drought prior to the tassling stage in corn growth; excessive pre-harvest heat which causes diminished oil production from soybeans; frost prior to a specific date; hail at any point prior to harvest, or excessive rains after crop maturation that inhibits or prohibits harvest.

In the above examples the state variable is defined as weather, and the conditioning parameters are defined in reference to specific times along the growth curve. In this study the effects of heat and rainfall on crop yields is measured from June 1 to August 31 which captures a broad spectrum of risks. However we could have selected a specific month, week, or even day to assess the risks. This is because specific event risk is explicitly defined as a single insurable peril, which contributes marginally to total variance. Here the cause is insured, not the effect! Weather derivatives can target specific events whose marginal contributions to total risk are known to be high.

Economics and Weather Insurance

The insured can select a put option which would provide an indemnity if rainfall or heat falls below $\omega_{a,}$ a call option if rainfall exceeds ω_b, or both (a collar). In general the price of these contracts (in the absence of time value) would be

(1) $$V_{put} = \int^{\omega a} Z\,(\omega_a - \omega)f(\omega)d\,\omega \quad \text{for} \quad \omega < \omega_a$$

and

(2) $$V_{call} = {}_{\omega b}\int Z(\omega)\,(\omega - \omega_b)f(\omega)d\,\omega \quad \text{for} \quad \omega > \omega_b.$$

Equations (1) and (2) rely on several factors to be priced. First, $f(\omega)$ represents the probability distribution function which describes rainfall throughout the growing season; second the insured must have some idea of the specific event to be insured. For the put option in equation (1) the specific event is $\omega < \omega_a$, and for the call option in equation (2) the specific event is given by $\omega > \omega_b$ where ω_a and ω_b are strike levels. Finally, the third element is the value of **Z** which represents a constant payoff for each unit that the option expires in-the-money. Options of this type are similar to European call and put options and we will refer to them as European-type options. Alternatively **Z** may be a fixed payoff on a specific event. By setting $(\omega_a - \omega) = 1$ and $(\omega - \omega_b) = 1$ in equations (1) and (2) the options are converted to a form in which the premium equals the cumulative probability of the event happening times the payoff assigned to the event. Options of these types are similar to specific event insurance contracts.

In this section options of both types will be calculated. The European-type options will be priced using the 'burn-rate' approach which uses historical observations to predict current risks. This implicitly assumes that history will repeat itself in one form or another[1].

It is assumed that the hedger is a crop insurance corporation which faces the average yield risk in Oxford County Ontario. Daily rainfall and average daily temperatures were obtained from the Environment Canada weather station at Woodstock Ontario that is somewhat central to the county. Three years (1942, 1948, and 1972) are excluded from the analysis due to missing weather data (at least one observation missing). Cumulative heat units ranged from a high of 1,886 to a low of 929 with a mean of 1,532. Cumulative rainfall ranged from a high of 438 mm to a low of 107 mm with a mean of 250 mm. The specific event examined is the cumulative rainfall and cumulative degree-day heat units from approximately June 1 to August 31 as measured on a calendar day (rather than date) to avoid leap-year problems. Based on regressions (not presented in this paper) the crop insurer would face significant liabilities for corn and soybeans if heat units were below average. Likewise low rainfall would increase the liability for forage crops such as hay.

The prices of European-type put option are based on a payoff of $10,000/mm rain or $10,000/degree F. and are calculated for the following cases;

- A degree-day strike of 1,528 to hedge against average corn yields falling below the mean (125.19 bu./acre),
- A degree-day strike of 1,152 to hedge against county average corn yields falling below 95% of the mean (118.92 bu./acre),
- A degree-day strike of 1,545 to hedge against county average soybean yields falling below the mean (39.14 bu./acre),
- A degree-day strike of 1,265 to hedge against county average soybean yields falling below 95% of the mean (37.18 bu./acre),

[1] Elsewhere I have developed a pricing model that can use Black's options pricing model. The approach used here represents the current practices of brokers and insurers. The use of modern options pricing requires the existence of a weather index that spans the risks and that is marked to market on a daily basis. The approach differs from the burn-rate approach in that risks are measured by the volatility of a marked-to-market index rather than history. To this point brokers have believed that weather options could not be priced using Black or Black-Scholes. However in comparing the burn-rate approach to Black's model, the former appears to price weather derivatives higher than the latter.

- A degree-day strike of 1,024 to hedge against county average soybean yields falling below 90% of the mean (35.23 bu./acre),
- A cumulative rainfall strike of 249 mm to hedge against county average hay yields falling below the mean (4.13 tonnes./acre),
- A cumulative rainfall strike of 147 mm to hedge against county average hay yields falling below 95% of the mean (3.9 tonnes/acre).

Specific Event Options

Alternative options can be more specific than the European-Type options. Specific event options will have a fixed payoff per event but the contract may allow for two or more events over the insured time horizon. To illustrate the pricing of specific event risks the following specific event options are evaluated for the June 1 to August 31 period;

- To reinsure against heat related stresses payment of $500,000 is made if average daily temperatures exceed 75 degrees Fahrenheit for 5 days straight. Up to four non-overlapping events are allowed.
- To reinsure against heat related stresses a payment of $1,000,000 is made if cumulative heat units between June 1 and August 31 is greater than 1,700.
- To reinsure against heat related stresses a payment of $1,000,000 is made if cumulative heat units between June 1 and August 31 does not exceed 1,200.
- To reinsure against drought related stresses a payment of $100,000 is made if zero rainfall is recorded during any 14-day period for up to four non-overlapping events.
- To reinsure against drought related stresses a payment of $1,000,000 is made if cumulative rainfall between June 1 and August 31 is less than 150mm.

Results of Insurance Calculations

The results of the premium calculations are found in Tables 1 and 2. In Table 1 results for European-type options, computed using the burn rate, are presented. For the two rainfall derivatives with strikes at 249 mm and 147 mm respectively, and payoffs of $10,000 per mm in-the-money, the estimated premiums were $299,613 and $18,290 respectively. The premiums reflect the rarity of the second event over the first. For Woodstock the likelihood of rainfall being less than 249 mm was significantly higher than the likelihood of rainfall being less than 147. In fact, the mean indemnity was paid on an average of 29.96 mm with a maximum payoff on 142.5 mm in the former case, while the mean payoff was on only 1.83 mm with a maximum of 40.5 mm in the latter case. The maximum premium that could have been paid out with the data used was $1,425,00 and $405,000. Even with the lower strike and its low probability of expiring in-the-money the payoff could be quite sizeable. Rare events do happen.

The degree-day put spread options based on a crop heat unit of mean daily temperatures in excess of 50 F. also exhibit properties consistent with modern options pricing. For a strike of 1,545 F the estimated premium is $696,854 with a maximum potential payoff of $6,160,200. As the specific event becomes rarer the likelihood of the option expiring in-the-money decreases as does the premium. For a strike of 1,265 F. the premium falls to $437,908 with a maximum of $3,360,200, and a strike of 1,024 F. results in a premium of only $16,105 with a maximum of $950,200.

Table 2 presents results for specific event options. The first case is an option that pays $1,000,000 if rainfall from June 1 through August 31 is less than or equal to 150mm. The expected payoff and premium for this product is $80,645 and the event occurred with a likelihood of about 8%. The second option is a multiple event option that pays $100,000 if there is zero mm of rainfall in any non-contiguous 14-day period. In only 13% of the years did this event happen once and in only 8% did it happen twice. Although the option would allow for up to four events the likelihood of more than two events was zero. The premium on this product was $29,032.

The third specific event is a heat trigger that pays $500,000 if the mean daily temperature exceeds 75F for 5 days straight. This is expected to occur once in approximately 19% of the years, twice in only 6.8% of the years and not at all in about 75% of the years. The premium calculated for this product was $161,017 and the maximum payoff would have been $1,000,000. The fourth event is based on cumulative heat units above 1,700 as at August 31 and is therefore like a call option. If the actual cumulative heat units are greater than 1,700 then a payoff of $1,000,000 is received. In only 13.6% of the years did this event happen. The premium was $135,593. The last specific event example hedges excessive cooling. If, on August 31, cumulative heat units are less than 1,200 a payment of $1,000,000 is made. This event happened only about 1.6% of the time and the premium is only $16,949.

Discussion and Conclusions

An emerging market for weather-based derivative products could offer new hedging possibilities for agricultural production. Unlike commodity hedges using futures contracts and options on prices, the use of weather derivatives provides a market mechanism for insuring against output. The efficacy of weather derivatives on rainfall or heat depend on a number of factors of which the most important is the identification of specific risks. In this paper daily rainfall and temperature data from 1935 to 1996 at Woodstock Ontario was examined. With these products the underlying risk is not in crop yield variability but in the source of that variability. The advantage to a crop insurer or reinsurer is that a payoff based on weather does not require any proof of damage.

Based on the notion of specific event risks a number of different insurance/derivative contracts were introduced and their premiums (before transaction costs) computed. The results showed, as expected, that insuring weather has properties similar to conventional options. The higher the strike prices the higher the potential payoff and therefore the higher the premium. For example a cumulative degree-day put spread calculated from historical data and a payoff of $10,000 for every degree the option expired in-the-money was priced at $696,854 for a strike of 1,545 degrees, whereas a put option with a lower strike of only 1,024 degrees cost only $16,105.

It was shown that weather derivatives need not be confined to European-type options. Single payoff and multiple event contracts could also be written. An example of drought insurance, which provided a payoff of $1,000,000 if the expiry date cumulative rainfall was less than 150 mm had a premium of $80,645. A multiple (4) event call option that had a payoff of $500,00 if mean daily temperature exceeded 75F for 5 days straight had a premium of $161,017.

The advantages of weather insurance are that the insured event relies on authoritative data and because it does there are many crop reinsurers and other financial institutions that are willing to sell or broker weather derivative products. There is likely an excess supply of sellers, because potential buyers may not be aware of the new products.

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Table 1: European-Type Option Calculations For Rainfall And Crop Heat Units							
Item	**Rainfall (mm)**		**Crop Heat Units (Degrees Fahrenheit > 50 degrees)**				
Strike Level	249	147	1,545	1,528	1,265	1,152	1,024
Mean units in- the-money	29.96	1.83	69.69	61.06	6.15	3.78	1.61
Standard Deviation of Units in-the-money	41.00	7.58	108.41	103.15	43.79	29.03	12.37
Minimum Units	0	0	0	0	0	0	0
Maximum Units	142.5	40.5	616.02	599.02	336.02	223.02	95.02
Premium ($)	299,613	18,290	696,854	610,624	61,454	37,800	16,105
Standard Deviation, Premium ($)	419,649	75,750	1,084,072	1,031,539	437,908	290,347	123,706
Minimum Premium ($)	0	0	0	0	0	0	0
Maximum Premium($)	1,425,000	405,000	6,160,200	5,990,200	3,360,200	2,230,200	950,000

Table 2: Specific And Multiple Event Rainfall And Heat Unit Premium Calculations					
	Rainfall (mm)		**% 0 Events Occurred/Year**		
Item	**< 150 mm cumulative**	**0 mm/day**	**> 75F**	**> 1,700 Heat Units**	**< 1,200 Heat Units**
# Events	1	4	4	1	1
Length of Event (days)	term	14	5	term	term
Payoff /Event ($)	1,000,000	100,000	500,00	1,000,000	1,000,000
Premium ($)	$80,645	29,032	161,017	135,593	$16,949
% 0 Events Occurred/Year	92%	79%	74.6%	87.1%	98.4%
% 1 Event Occurred/Year	8%	13%	18.6%	12.9%	1.6%
% 2 Events Occurred/Year	0	8%	6.8%	0	0
% 3 or 4 Events Occurred/Year	0	0	0	0	0