9.1 Introduction

Weather Derivatives could be structured as swaps, call options or put options based on a particular weather index. The structure of the derivatives could be innovatively designed to manage weather-related risks of various kinds. The market would consist of not only farmers, but a large number of players whose businesses are affected in some form or the other by the vagaries of weather. Insurance and reinsurance companies would also be market players.

While the scope of weather derivatives is enormous, there are the accompanying challenges of valuing and pricing the derivatives to not only be financially viable instruments, but also be instruments with appeal to the financially weaker sections of society, viz. the farmers.

Whilst the methods of valuing equity options are fairly well defined, this is not so in the case of weather derivatives. The major reason is that, unlike as in equity options, we cannot assign a monetary value to the underlying ie. the weather, in the case of weather derivatives. Thus a no-arbitrage option pricing model such as the Black-Scholes model (Black and Scholes, 1973) is not a practical pricing tool for weather derivatives.

In the case of weather derivatives, two methods of valuation can be perceived. The first is to determine the value based on the probabilities of possible outcomes. This is called actuarial pricing. The second is to use market price as the value. Obviously the second method would only be possible if an observable market for weather options exists. This not being the case in India at present, weather options pricing based on actuarial techniques is probably the way forward.

An interesting observation made by Jewson and Brix (2005) relates to the applicability of the Capital Asset Pricing Model (Sharpe, 1964) to weather derivatives. CAPM states that the excess return from an investment, over a risk-free rate is proportional to the relationship between the performance of the
instrument and the performance of some wider market. So investments with a higher correlation with the wider market would have a higher return, whilst those with low correlations would have a return which would be closer to the risk-free rate. According to the CAPM then, we cannot have instruments which have a low correlation with the wider market, and at the same time have a high return above the risk-free rate.

As can easily be comprehended, there would be very little correlation between the weather and the financial markets. Thus, according to the CAPM, the low correlation should imply that the returns from weather derivatives should actually be close to the risk-free rate. However, Jewson and Brix (2005) point out that, in-fact, the CAPM does not apply very well in the weather market mainly because weather derivatives are not considered as an investment class by most investors, and so the lower demand results in a lower valuation than the low correlation and the CAPM may suggest. Also those organisations which invest in weather derivatives expect them to yield a decent return above the risk-free rate, inspite of the low correlation with other assets.

Thus weather derivatives could be an investment with a low correlation with the wider market, but with a higher than expected return.

9.2 The contracts

Weather derivatives would generally be of three types:

(i) Swaps
(ii) Futures
(iii) Call/Put options

Commonly used indices could be based on temperature, rainfall, snowfall etc. For the purpose of this thesis, we will consider weather derivatives in the form of call/put options because these are the types of contracts that we would expect small farmers to be interested in. Also, we will consider indices based on rainfall.

In the absence of a market in the Indian context, we will be discussing a hypothetical market, and how a contract could be structured when weather derivative trading is introduced.

We define a rainfall index future as an agreement to buy or sell the value of the index at a pre-defined date in the future. A rainfall call option would be a
contract where the owner has the right (but not the obligation) to buy a futures contract at a price which is correlated to a pre-specified ‘strike’ on the index. Similarly, a put option would be a contract where the owner has the right (but not an obligation) to sell a futures contract at a price which is correlated to the ‘strike’ on the index.

The buyer of a put option, for example, pays the seller a premium upfront i.e. at the beginning of the contract. In the situation that the actual rainfall at the end of the contract is less than the strike value of the index, the option would be in-the-money and the buyer of the option may want to exercise the option.

In the contract, we would also specify a ‘tick size’, which would be the amount of money in rupees that the holder of a put option receives for every millimetre that the actual rainfall is below the strike level, in the period specified in the contract.

If $K$ denotes the strike level (on the index), $x$ the amount of actual rainfall (the index), $t$ the tick size and $n$ the period, then the payout of a put option would be:

$$ P_n = \begin{cases} 0 & x > K \\ t(K - x) & x \leq K \end{cases} $$

We would also assume that the options are European style, which means that they can only be exercised on the date of expiration of the contract period.

The gain or loss which would accrue to someone who is long on a put option, is depicted in fig 9.1.
9.3 Pricing

One of the main reasons for the upsurge in volumes in the financial derivatives market in the 1980s was the general acceptance of the Black-Scholes model for pricing of options. Such a common model is still not in place in the case of weather derivatives, which has an acceptance across all prospective players.

This highlights the need for a simple method for pricing weather derivatives, so that it can be universally applied and is transparent enough for the players in the market to comprehend it.

9.3.1 Actuarial techniques

The conventional actuarial technique is a purely statistical approach where historical records of the rainfall are used as a source for calculation of the payout $p_n$. To this is added the administrative costs or overheads, in order to determine the fair value of the option premium.

*Burn Analysis.* This is a simple method, where the pricing of the option is based on an analysis of how a contract would have performed in hypothetical markets in the past. In this case, the historical settlement values are directly converted into payouts. These historical payouts are then used to find the mean and the standard deviation of the payouts.
Index modelling. On the other hand, index modelling involves the fitting of a distribution to the historical index values. This allows the model to include outcomes which might not have actually occurred in the past. The steps which would be followed would typically be:

(i) Obtain historical data of the weather parameter being considered, preferably on a daily basis.
(ii) Clean the data and aggregate it year-wise for the periods of the proposed contract.
(iii) Fit a statistical distribution to the historical values.
(iv) Do a monte-carlo simulation from the distribution
(v) Convert each simulated figure of the aggregate value of the weather parameter into a simulated payout.
(vi) Determine the mean and the standard deviation of the simulated payouts.
(vii) Add a percentage of the mean payout value to cover administrative and other costs, in order to determine the fair price of the option

We can thus determine the price of a weather derivative through simple statistical analysis of historical weather data.

Of course, this method does not take into account any market consideration whatsoever.

A short discussion of literature in respect of weather derivatives pricing is given below.

Hamisultane (2006b) has pointed out that since there now exist a fair number of market contracts in weather derivatives, taking these into consideration would improve the prediction pricing of weather derivatives.

Cao and Wei (2004), while discussing temperature-index related weather derivatives, find that temperature is significantly correlated with energy consumption and that the market price of weather risk is significantly different from zero. They suggest the use of a consumption based asset pricing model to price weather derivatives.
Richards et al. (2004) use a model where a utility function, which depends on a stochastic consumption, is maximised for individuals.

Hamisultane (2006a) has estimated a relative risk aversion coefficient and used it in the above model.

Yang et al. (2003) adopt the indifference pricing approach to price weather derivatives considering the marginal changes they cause to the investor’s asset portfolio. Through simulations, they illustrate the portfolio effects on pricing of weather derivatives.

### 9.4 Pricing a put option on rainfall at Jhalawar

We consider data from the point of view of farmers growing Soyabean in district Jhalawar in the state of Rajasthan.

Soyabean is grown in the Kharif season, usually sown in the month of June. It has a germination stage of about three weeks, a vegetative growth stage of about twelve weeks and a grain formation/maturity phase of about four weeks. The crop is usually harvested in end October/November.

Data for soyabean yield in Jhalawar district was obtained from the Directorate of Economics and Statistics, Government of Rajasthan, Jaipur. Whilst data was obtained for a period of 23 years, i.e., from 1982 to 2004, an obviously discernible change in the yield pattern was noticeable in the periods prior to 1990 and post 1990. This is attributable to the use of a shorter duration, high yield variety from 1989-90 onwards (Deosthali et al., 2005). Based on this, it was decided to use the yield data from 1990 onwards.

Data for rainfall was purchased from the India Meteorological Department. Daily rainfall data for Jhalawar was obtained for the period 1990 to 2004. However, there were gaps in the data and a fair amount of cleaning was resorted to. Daily rainfall data for the 15 years was then aggregated, in order to obtain the rainfall in the period 16 June to 15 October in each year.

Yield data was regressed against rainfall data for the 15 year period and a second order polynomial was fitted. Leaving out outliers, another regression was done with the remaining data. The result is shown in Fig 9.2.
The Minimum Support Price announced each year by the government is assumed to be the price which a farmer can obtain for his produce. The MSP announced for each of the years being considered in the data set was inflated to 2004 levels.

We now take the case of a farmer with one hectare of land on which he has grown soyabean and who wishes to buy put options on rainfall in order to hedge his yield risk. We also initially assume that he is willing to pay 8.8% of the maximum payout as premium for the option. This is the figure established through the willingness to pay analysis of the survey data obtained from villages in Jhalawar and Tonk districts as indicated in Chapter 7. We also assume that the average yield of soyabean in district Jhalawar is what the farmer obtains from his land under cultivation.

Based on past data, we can see that the average rainfall at Jhalawar in the period 16 June to 15 October was 870.18 mm, with the highest rainfall in this period being 1098.6 mm in 1993 and the lowest being 572 mm in the year 2002. We also note that the farmer would have had a mean yield of 0.99 tonnes of soyabean from his land over the 12 years being considered, with the highest
Pricing: options on rainfall

yield being 1.39 tonnes in the year 2004, and the lowest being 0.50 tonnes in the year 2002.

The correlation between the rainfall and the yield is seen to be 0.71.

Using the values of MSP, inflated to 2004, the farmer would have received a mean sale income of Rs 922.33, with the highest being Rs 1289.69 in 2004 and the lowest being Rs 472.03 in the year 2002. The average deviation of the sale income of the farmer in the period under consideration is 235.66.

We now consider a hypothetical situation with the availability of rainfall options on an index which is the aggregate rainfall in the period 16 June to 15 October, and where the farmer has been long in one put option every year in the past.

The premium which could be charged from the farmer can be calculated from:

\[ P = \text{WTP} \times (K-o) \times t \]

where 
- \( P \) = premium
- \( \text{WTP} \) = farmer's willingness to pay
- \( t \) = tick size
- \( K \) = strike value

We take \( K = 870.18 \), which is the mean of the rainfall in each year. The tick size would need to be specified in the contract. Varying the tick size would not only vary the premium, but would also vary the net income of the farmer in two ways: first because of a variation in the income from the exercise of the option (when it is in-the-money) and second because of the variation in the premium itself, which the farmer pays up-front.

The fair price of the option would be the mean of the payout against the sale of the option in the period considered. In our method of determining the price of the option, we do a sensitivity analysis on the variation of the tick size, and determine a tick size which gives us the maximum reduction in the average deviation of the farmer's income. In other words, we are striving for a situation where the intention is to steady the farmer's income to the largest extent possible by hedging the weather risk to his crop yield.
With this social welfare target in mind, we will try to see whether the amount of premium determined through using the willingness to pay figures, determined through our survey in Jhalawar, would make the put option financially viable from the point of view of the seller of the option.

Payout from a put option on the rainfall index is taken as:

\[ \text{OPTNINC} = t \cdot \max(0, K - x) \]

Where \( x \) = actual rainfall
\( t \) = tick size

Through a sensitivity analysis, the ideal value of the tick size is determined to be Rs 2.40 (shown in Fig 9.3). This implies that the put option, when exercised, would receive a payout of Rs 2.40 for every mm that the actual aggregate rainfall in the period 16 June to 15 October is less than the strike value (which we take as the mean value of the rainfall in the 12 year period). Accordingly, the maximum premium which the farmer would be willing to pay is determined to be Rs 183.70. This is for a maximum possible payout of Rs 2088.43.

With the above contract specifications, the incomes of a farmer at Jhalawar, growing soyabean on one hectare of land, in the 12 years being considered in the past, without hedging, and with hedging through being long on one put option, are indicated in fig 9.4. Also indicated on the same graph are the gain/loss in each of the years which the farmer would have had.
9.4.1 Monte-Carlo simulation

We now proceed to see if an option with this structure would be financially viable for the seller of a put option.

Since the amount of data available (12 years) is small, a monte-carlo simulation was done to generate values for the payout from the option with random values for the actual rainfall. This was done on EXCEL, using the RISKSIM add-in. A total of 500 simulations were done.

The rainfall data is assumed to be normally distributed. To corroborate this assumption, the best-fitted probability density function (pdf) model was identified using the goodness-of-fit criteria through MINITAB. In all 7 different parametric pdfs were fitted. The estimated p-values for different models for the rainfall data is provided in Table 9.1.
Table 9.1 Different probability models with p-values for the rainfall data (the best fit model has been shown in bold)

<table>
<thead>
<tr>
<th>Distribution</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>0.867</td>
</tr>
<tr>
<td>Lognormal</td>
<td>0.616</td>
</tr>
<tr>
<td>Exponential</td>
<td>&lt; 0.003</td>
</tr>
<tr>
<td>Gamma</td>
<td>&gt; 0.25</td>
</tr>
<tr>
<td>Weibull</td>
<td>&gt; 0.25</td>
</tr>
<tr>
<td>Logistic</td>
<td>&gt; 0.25</td>
</tr>
<tr>
<td>Loglogistic</td>
<td>&gt; 0.25</td>
</tr>
</tbody>
</table>

The mean value of the payout to the put option over 500 simulations was determined to be Rs 161.07 when the strike value is fixed as the mean of the rainfall in the 12 years considered.

This implies that the seller of the option has a surplus of 14.05% over the mean payout, if he collects a premium of 8.8%, which is the maximum willingness to pay indicated by the farmers in Jhalawar for hedging weather risks to yield. This amount is likely to be adequate to cover administrative and other costs.

If the strike is taken as 95% of the mean, then the mean value of the payout to the put option over 500 simulations is Rs 153.64, giving a larger surplus to the seller of the option.

The results of the simulations are given in Appendix III to this thesis.

The figures derived indicate the feasibility of introducing weather derivatives as an investment option for small farmers to hedge the weather related yield risk which they face.