4.1 PRICING A FINANCIAL INSTRUMENT TO GUARANTEE THE ACCURACY OF A WEATHER FORECAST

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1. INTRODUCTION

"… knowledge-based systems and other AI (artificial intelligence) techniques are particularly useful for dealing with new developments in the financial environment. These techniques are extremely relevant where you have a changing world, and where you have new instruments being created where there is no past (trading) data, but there is a lot of information to be assembled and it really stretches the cognitive abilities of traders, portfolio managers and risk managers."

So concludes a recent analysis (Davidson, 2002) of AI advances in the financial markets. And, in an environment of an increasing emphasis on utilising techniques sourced in the financial markets to manage risk related to weather, it is a truly relevant statement.

2. BACKGROUND

The Australian Bureau of Meteorology's Melbourne office possesses data about the accuracy of its temperature forecasts stretching back over 40 years.

Customers receiving weather forecasts have, recently, become increasingly interested in the quality of the service provided. This reflects an overall trend in business towards implementing risk management strategies. These strategies include managing weather related risk.

Indeed, the US Company *Aquila* has a web site that presents several illustrations of the concept: http://www.guaranteedweather.com

The guarantee described in the present paper is that the forecast will be in error by no more than 3°C. The terms of the guarantee are that the seller of the guarantee will pay the buyer $100.00 for each 0.1°C greater than 3°C that the forecast is in error.

It is the purpose of the paper to develop an approach to pricing such a financial guarantee, and to provide it as a technique that is available on the web.

3. WEATHER DERIVATIVES

Clewlow *et al.* (2000) describe a derivative as "a financial product that derives its value from other more basic variables". These products include futures, forwards, call options, put options, and swaps.

They describe weather derivatives (Stern, 1992, 2001) as being similar "to conventional financial derivatives, the basic difference coming from the underlying variables that determine the payoffs", such as temperature, precipitation, wind, Heating Degree Days (HDDs), and Cooling Degree Days (CDDs).

4. THE INSTRUMENT

The instrument, that is the subject of the present paper, is made up of a combination of a call option and a put option about the next day's maximum temperature at Melbourne, the "strikes" being set respectively 3°C above and below the forecast temperature.

The taker of this option combination receives $100 for each 0.1°C that the observed temperature is above or below the respective strikes.

5. APPROACHES TO PRICING DERIVATIVES

There are three approaches that may be applied to the pricing of derivatives. These are:

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- Historical simulation (applying "burn analysis");
- Direct modelling of the underlying variable’s distribution (assuming, for example, that the variable's distribution is normal); and,
- Indirect modelling of the underlying variable’s distribution (via a Monte Carlo technique).

Direct modelling is chosen for the current exercise, the distribution of forecast errors being assumed to be normal.

6. THE APPROACH USED

In a paper to be presented at a subsequent meeting, Dawkins and Stern (2003) show that the magnitude of the forecast errors is largely a function of season (Fig 1) and synoptic pattern (Fig 2).

In another paper to be presented at the current meeting, Dahni (2003) describes an automated technique for "typing" synoptic patterns.

The approach used is as follows:

- The forecast verification data is stratified according to month, and also according to the nature of the prevailing atmospheric circulation - cyclonicity, direction and strength of the surface flow.
- The distribution of the magnitude of forecast errors for each month (and also for each synoptic pattern type) is noted.
- This distribution is adjusted in order to take into account a long-term downward trend in the magnitude of the errors;
- The distribution of forecast errors is assumed to be normal for each data subset, and a "fair value" price for the option combination for each month and each circulation type is then obtained.

7. EXAMPLE

The example we shall use to illustrate the methodology is a forecast produced during the month of January, associated with a synoptic type flow possessing the following characteristics:

- weak strength;
- cyclonic (curvature);
- from the north-north-west.

Over the 40-year period (1961-2000), occurrences of such a flow across SE Australia (over all months of the year) have been accompanied by a set of maximum temperature forecasts with an RMS error of 2.70°C.

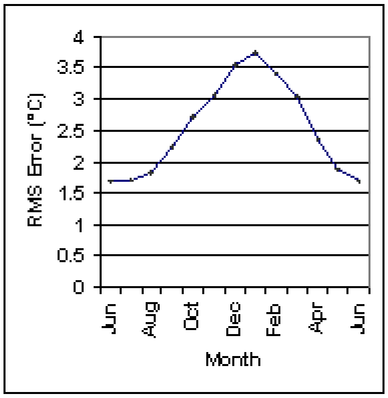


Fig 1 Seasonal variation in RMS errors (°C) for Melbourne day-1 maximum temperature forecasts 1961-2000 (after Dawkins and Stern, 2003).

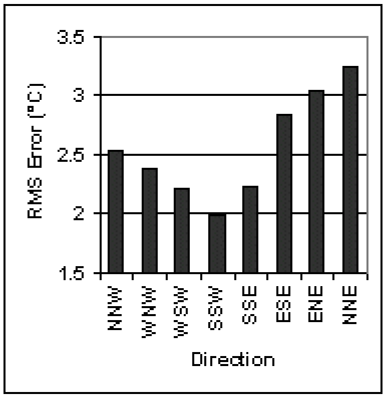


Fig 2 RMS Errors (°C) for Melbourne day-1 maximum temperature forecasts (1961-2000) - issued in association with moderate cyclonic flow from each of eight directions (after Dawkins and Stern, 2003).

More recently (1991-2000), such a flow has been accompanied by an RMS error of (a much reduced) 2.26°C.

It is then assumed that the forecast performance during the period 1991-2000 better represents what one might anticipate to be the current level of performance, than does the forecast performance over the 1961-2000 period.

It is also assumed that the proportional improvement in forecasting for each individual month (January, February, March etc.) is the same, that is, a proportional decrease in RMS error of (2.26/2.70)=(0.84) in the current case.

The monthly RMS error calculated over the 1961-2000 period for the current synoptic type and the current month (3.32°C in this case) is then multiplied by the ratio (0.84) in order to achieve an estimate of the likely RMS error for the current forecast.

So, the case of a January cyclonic weak north-north-west synoptic flow yields (0.84x3.32)=2.79°C for our estimated RMS error.

It is then assumed that the errors are normally distributed and, utilising areas under the standard normal curve, one calculates the expected return on the guarantee to be $410.

This procedure is then repeated for all months and for all synoptic patterns.

8. THE WEB SITE

A web site is developed (Fig 3) in order that :

- potential "customers" may readily obtain a price for the instrument; and,
- researchers may test its output.

This may be viewed and tested at
http://www.weather-climate.com/guarantee.html

9. VERIFICATION

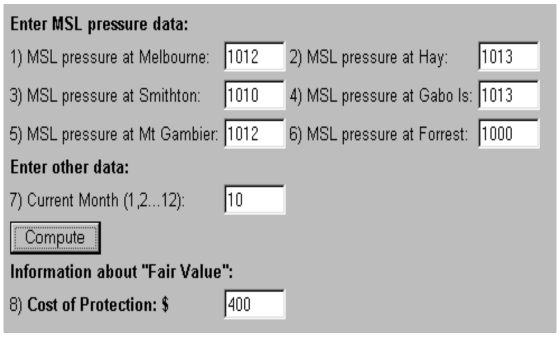
It was considered that if, over a large number of cases, writers of the option combination not make either a significant profit or a significant loss, the validity of the "fair value" price would be demonstrated.

The instrument's validity was then tested by calculating the "fair value" price on independent cases taken for the entire year of 2001.

However, from an analysis of all of the year 2001 cases, it was determined that writers of the option combination would have received $75,574 over the year, while paying out only $23,800.

Nevertheless, this substantial profit (over 200% return) is not necessarily suggesting a possible flaw in the valuation technique. On the contrary, it may be explained in terms of the spectacular improvement in the accuracy of forecasts achieved during 2001 (Fig 4).

One may show that had the forecasts been of similar skill to those of previous years, the payout would have been much closer to the monies received. The profit achieved by the option writers can, therefore, be explained in terms of that increased skill.



Enter MSL pressure data:
1) MSL pressure at Melbourne: 1012
2) MSL pressure at Hay: 1013
3) MSL pressure at Smithton: 1010
4) MSL pressure at Gabo Is: 1013
5) MSL pressure at Mt Gambier: 1012
6) MSL pressure at Forrest: 1000
Enter other data:
7) Current Month (1,2...12): 10
Information about "Fair Value":
8) **Cost of Protection: $** 400

Fig 3 A view of the web site.

10. CONCLUSION

A methodology to price a financial guarantee about the accuracy of a forecast has been described and demonstrated with "real" data.

It has been shown that had such a guarantee been applied to day-1 maximum temperature forecasts issued during 2001 for Melbourne, providers of the guarantee would have made a substantial profit (on account of the increased skill displayed by the forecasts).

11. REFERENCES

Clewlow, L., Strickland, C. and Booth, M., 2000: Weather Derivatives. Short business programs. Published by *University of Technology, Sydney*.

Dahni, R. R., 2003: An automated synoptic typing system using archived and real-time NWP model output. *19th Conference on Interactive Information Processing Systems*, *Amer. Meteor. Soc.,* Long Beach, California.

Davidson, C., 2002: Artificial intelligence advances. *Risk*, September 2002, pp 26-28.

Dawkins, S. S. and Stern, H., 2003: Trends and volatility in the accuracy of temperature forecasts. Submitted to the *7th International Conference on Southern Hemisphere Meteorology and Oceanography, Amer. Meteor. Soc.,* Wellington, New Zealand.

Stern, H., 1992: The likelihood of climate change: a methodology to assess the risk and the appropriate defence. *5th International Meeting on Statistical Climatology, Amer. Meteor. Soc.,* Toronto, Canada.

Stern, H., 2001: The application of weather derivatives to mitigate the financial risk of climate variability, extreme precipitation events and extreme temperature events. *Symposium on climate variations, the oceans and societal impacts, Amer. Meteor. Soc.,* Albuquerque, New Mexico.

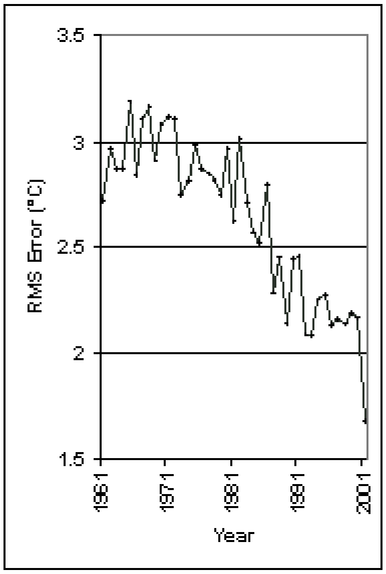


Fig 4 Annual RMS Errors (°C) for Melbourne day-1 maximum temperature forecasts (1961-2001) - note the sharp decrease at the end of the verification period (after Dawkins and Stern, 2003).