WEATHER DERIVATIVES.

WHY THEY ARE APPLICABLE TO YOU.

Case Study:*

EVALUATING THE COST OF PROTECTING AGAINST GLOBAL CLIMATE CHANGE: OPTIONS PRICING THEORY AND WEATHER DERIVATIVES

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1. INTRODUCTION

In a 1992 paper presented to the 5th International Meeting on Statistical Climatology (Stern, 1992), the author introduced a methodology for calculating the cost of protecting against the onset of global warming (Australian Greenhouse Office, 2002; Hennessy *et al.*, 2002; International Panel on Climate Change (IPCC), 2001; Stern, 2000; Victorian Government Department of Sustainability and Environment (DSE), 2004; and, Whetton *et al.*, 2002).

The paper, 'The likelihood of climate change: A methodology to assess the risk and the appropriate defence', was presented to the meeting held in Toronto, Canada, under the auspices of the American Meteorological Society. In this first application of what later was to become known as 'weather derivatives' (Clemmons, 1999; Clewlow, Strickland and Booth, 2000; Dawkins & Stern, 2003 & 2004; Dischell, 1998, 1999, 2000; Geman, 1999; Jain and Foster, 2000; Stern, 2001a, b, c & d; Stern 2002a & b; Stern and Dawkins, 2003 and 2004), the methodology used options pricing theory from the financial markets (Ritchken, 1987) to evaluate hedging and speculative instruments that may be applied to climate fluctuations.

Use of these financial instruments leads to those concerned being compensated provided they are on the correct side of the contract. Conversely, those on the wrong side of the contract would have to provide that compensation.

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2. BACKGROUND

Stern's (1992) methodology provided a tool whereby the cost of protecting against the risk faced could be evaluated (whether it is a case of determining that risk on a global scale, or on a company specific scale). Published data from the Carbon Dioxide Information Analysis Center (CDIAC, 1990), which showed a rise in the global mean temperature, were used in that evaluation.

Since the early 1990s, the global mean temperature appears to have risen further (Figure 1), and the methodology is 'revisited' with a view to recalculating the cost taking into account the additional, more recent, data.

The same examples are presented in the current paper as were used in the 1992 study, namely:

(1) Protecting against the risk of diminishing industrial output as a consequence of global warming; and,

(2) Protecting against the risk of the value of a company declining as a consequence of its earnings being adversely affected by global warming (for example, a manufacturer of ski equipment).

3. PURPOSE

Using a data set of land, air, and sea surface temperature anomalies (1861-2003), from the United Kingdom Meteorological Office, the purpose of the current work is to determine to what extent the cost of protection may have been rising [the data set is accessible at http://www.met-office.gov.uk/research/hadleycentre.html].

4. METHODOLOGY

The methodology used in the current work is the same as that used in the work presented in the 1992 paper.

Firstly, one regards the global mean temperature (GMT) in the same manner as one would a financial commodities futures contract and values it, and associated options, accordingly (Black, 1976; Gastineau, 1988). The theoretical value of such a futures contract is a function of 'holding costs minus income generated by the underlying instrument'. To illustrate, the theoretical value of a share price index (SPI) futures contract is a function of 'interest rate minus dividend return from the underlying shares'.

The aforementioned process yields theoretical valuations. On this basis the theoretical value of a GMT futures contract will equal the dollar equivalent of the current GMT (for example, the theoretical value of a GMT futures contract, when the GMT is 287.79K, would be $287.79).

Secondly, one assumes that GMT futures contracts are available to be bought and sold and that associated put and call option contracts (Gastineau, 1988) are available to be written or taken, and so alter the risk-return characteristics associated with the GMT contract.

The strategy, therefore, is to establish the economic consequences of movements in the GMT, these economic consequences being applied across the complete range of scales; that is, from the global economy down to the smallest company (for example, a ski equipment manufacturer).

These economic consequences can be replicated in a combination of GMT futures contracts and an associated set of 'written' and 'taken' put and call option contracts at various strikes and expiry dates.

The use of the methodology presented derives from an assumption that the two time series (SPI and GMT) follow a "random walk" principle (Cheng and Deets, 1971 and Gordon, 1991), that is, the value of the next element in the series is independent of preceding values.

However, the operation of financial markets sometimes leads to significant departures from the theoretical value of futures contracts, such departures being a function of anticipated movements in the value of the underlying commodity.

Although it may be argued that the market would evaluate the cost of protection against adverse consequences of global warming by taking into account the spread of predictions from global climate models (GCMs), the running of GCMs is quite analogous to the efforts that are undertaken to forecast the movement of the SPI. Rarely do the contracts significantly vary in value from the theoretical. For this reason, the current work utilises theoretical valuations.

5. ILLUSTRATIVE EXAMPLES

5.1 *Two Illustrative Examples*

The two illustrative examples are the same as those presented in the 1992 paper, except that, for the current paper, the 1861-2003 data from the United Kingdom Meteorological Office are used.

5.2 *Example 1*

Protecting against the risk of diminishing industrial output as a consequence of global warming.

Assumptions -

1. That the long term GMT is 288K (approximately 15°C) and that departures given by the United Kingdom Meteorological Office data series are regarded as being from that figure (for example, the 2003 element in the data series, +0.49, is represented by 288.49K).
2. That the protection is required against the risk of a diminishing (that is, a slowdown) in the increase in the world's industrial output that would have occurred, except for the adverse effects of global warming.
3. That the rate of increase in industrial output is unaffected by global warming as the GMT rises, until the temperature reaches a departure from the long term of +1.34°C (or 1.00°C above the 1988 CDIAC reading of +0.34°C), that is, 289.34K. A temperature increase from this point is assumed to adversely affect industrial output, causing it to decline in a linear manner as GMT rises further to +2.34°C (290.34K), at which point the annual rate of increase in industrial output is reduced to zero. Continued rise in GMT from this point is assumed to lead to an adverse effect increasing at the same rate. So, by the time the GMT departure is +3.34°C (291.34K), the rate of decline in global industrial output is equivalent to the current rate of increase. Note that this scenario is consistent with GCM output (Bureau of Meteorology, 1992), and also with the range of possibilities suggested by the Intergovernmental Panel on Climate Change (IPCC, 2001). Figure 2 illustrates this hypothetical scenario.
4. Protection is required for a period of 100 years.

Calculation -

This is equivalent to calculating the cost of an American call option contract on the value of a futures GMT contract with the following characteristics:

- Spot = Current GMT (this is regarded as the GMT for the most recent year, 2003, which has a value of 288.49K)
- Strike = 289.34K
- Standard Deviation of Returns (Volatility) = 0.000436 (based on the United Kingdom Meteorological Office data series)
- Interest rate = 0% (assuming that the only money which changes hands is that associated with variation margins).

Figure 3 illustrates the pay-off chart for this call option contract.

Utilising the Black and Scholes (1973) call option formula[1], as modified for future style options (Gastineau, 1988)[2], the calculation yields $0.1878 for 2003 - see also Black (1976).

So, for protection under the aforementioned assumptions, the full cost of protection is $18.78 for every $100 of the future rate of industrial growth, or 18.78% of that rate of industrial growth.

5.3 *Example 2*

Protecting against the risk of the value of a company declining as a consequence of its earnings being adversely affected by global warming (for example, a manufacturer of ski equipment).

Assumptions -

1. That the long term GMT is 288K (approximately 15°C) and that departures given by the United Kingdom Meteorological Office data series are regarded as being from that figure (for example, the 2003 element in the data series, +0.49, is represented by 288.49K).
2. That the protection is required against a decrease in the value of a company, that decrease which occurs as a consequence of GMT rising.
3. That the value is unaffected by global warming as the GMT rises, until the temperature reaches a departure from the long term of +1.34°C (or 1.00°C above the 1988 CDIAC reading of +0.34°C), that is, 289.34K. A temperature increase from this point is assumed to adversely affect company value, causing it to decline in a linear manner as GMT rises further to +2.34°C (290.34K), at which point the value is reduced to zero. Continued rise in GMT from this point has no further effect upon the company's value, as it cannot decline in value below zero. Figure 4 illustrates this hypothetical scenario.
4. Protection is required for a period of 100 years.

Calculation -

This is equivalent to calculating the difference between the cost of two American call option contracts on the value of a futures GMT contract with the following characteristics:

First contract -

This is the same contract as the one valued in Section 5.2, hence, its value is $0.1878.

Second contract -

- Spot = Current GMT (this is regarded as the GMT for the most recent year, 2003, which has a value of 288.49K)
- Strike = 290.34K
- Standard Deviation of Returns (Volatility) = 0.000436 (based on the United Kingdom Meteorological Office data series)
- Interest rate = 0%

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[1] C = HS - B

where

C = call option value

H = N(d_1), where N( ) is the cumulative standard normal distribution function, namely,

$$F(x) = \Phi(x) = (2\pi)^{-1/2} \int_{-\infty}^{x} \exp(-z^2/2)dz$$

[source: http://www.id.unizh.ch/software/unix/statmath/sas/sasdoc/stat/chap39/sect17.htm]

S = price

X = strike

R = interest rate

σ = standard deviation of returns (volatility)

T = time to expiry

$d_1 = ((\ln(S/X)+(R+\sigma^2/2)T)/(\sigma\sqrt{T})$

$d_2 = d_1-\sigma\sqrt{T}$

$H = N(d_1)$

$B = X\exp(-RT)\, N(d_2)$

[2] Gastineau (1988) proposes a "future style option" contract to replace many conventional options on futures contracts where, "unlike with conventional options, the buyer of the futures style option does not prepay the premium. Buyers and sellers post margin as in a futures contract, and the option premium is marked to the market daily. Valuation differs from conventional options primarily in the analysis of cash flows associated with the buyer's premium non-payment". This is the reason for employing the assumption of an interest rate of 0%.

Utilising the Black and Scholes (1973) call option formula, as modified by Gastineau (1988) for futures contracts, the calculation yields $0.0399 - see also Black, 1976.

So, the cost of protection is the cost of the first contract (which is bought) minus the cost of the second contract (which is sold), namely, $0.1479, or 14.79% of the future value of the company. Note again that no money changes hands initially, and it is possible that only at the end of the options' life will settlement occur.

So, for protection under the aforementioned assumptions, the full cost of protection is $14.79 for every $100 of the future value of the company.

Figure 5 illustrates the pay-off chart for this call option contract combination (buying the first contract and selling the second contract).

6. THE GROWING COST OF PROTECTION

To illustrate the growing cost of implementing such protection strategies, Figure 6 presents the outcomes of calculations for the two examples from 1861 to 2003.

It shows, in the case of protecting against the risk of reduced industrial output, that the cost has risen from about 4 cents in the dollar at the beginning of the period (*circa* 1860), to about 9 cents in the dollar 100 years later (*circa* 1960), and thence the rate of rise has accelerated to reach about 19 cents in the dollar in 2003.

It shows, in the case of protecting against the risk of the value of a company declining, that the cost has risen from about 3 cents in the dollar at the beginning of the period (*circa* 1860), to about 7 cents in the dollar 100 years later (*circa* 1960), and thence the rate of rise has accelerated to reach about 15 cents in the dollar in 2003.

7. SUMMARY

A methodology for calculating the cost of protecting against the risk of financial loss associated with global warming has been presented.

The calculation procedure is based on the premise that the global mean temperature time series follows a "random walk".

One has then borrowed from financial markets, the behaviour of which are also regarded as "random walk", an option pricing model to value hedging and speculative instruments that might equally apply to climate fluctuations.

In valuing the climate fluctuation hedging and speculative instruments, wide-ranging assumptions are made. But, the methodology does provide a tool whereby the cost of the risk faced can be determined (whether it is the case of determining that risk on a global scale, or on a company specific scale).

It has been shown, both in the case of protecting against the risk of reduced global industrial output, and also in the case of protecting against the risk of the value of a company declining, that the cost of that protection has risen over the years, and that the rate of that rise has accelerated recently.

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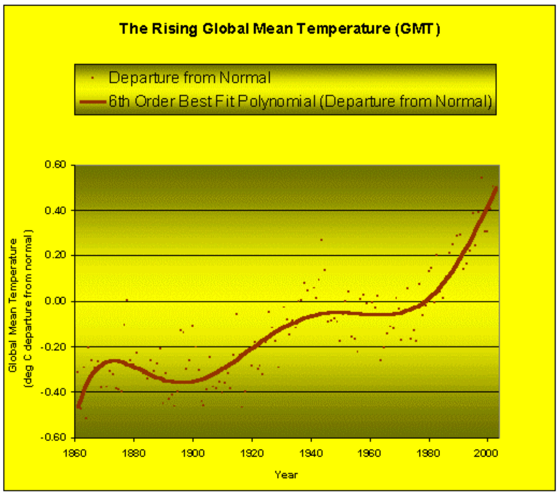

Figure 1 The rising global mean temperature (GMT).

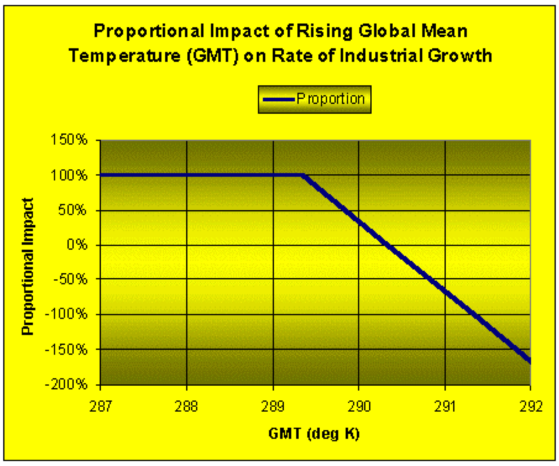

Figure 2 Illustration of hypothetical Example 1 scenario.

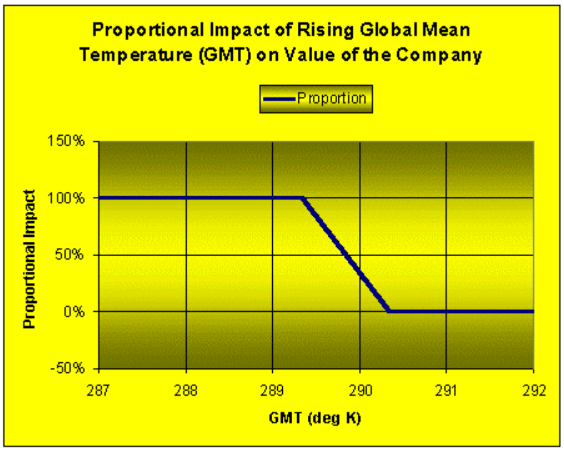

Figure 4 Illustration of hypothetical Example 2 scenario.

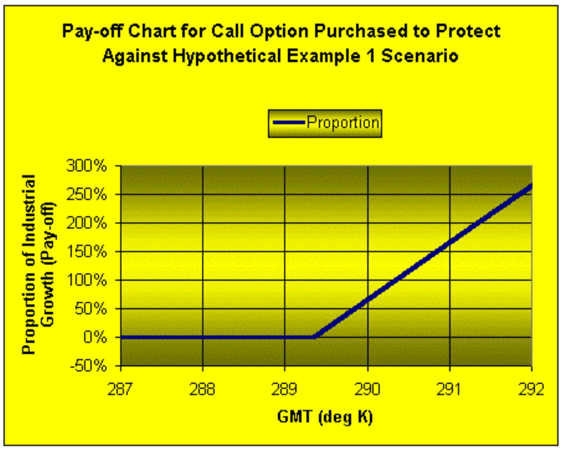

Figure 3 Illustration of the pay-off chart for the call option described in the hypothetical Example 1 scenario.

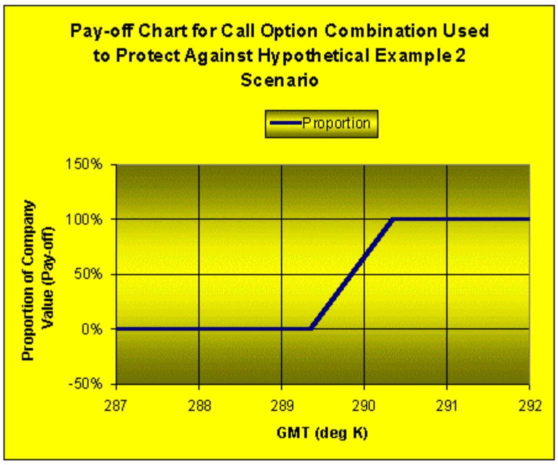

Figure 5 Illustration of the pay-off chart for the call option combination described in the hypothetical Example 2 scenario.

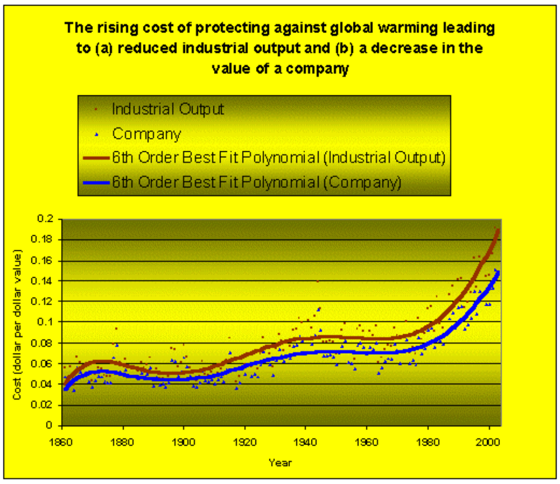

Figure 6 The rising cost of protecting against global warming.