

# **Financial Risk Management and Global Climate Change**

## **Introduction:**

The research proposed under this application falls into five categories:

- i) To carry out an assessment of the current ability of global financial and insurance markets to value and manage the risks implied by global climate change. Particular attention will be paid to the distinction between insurable and non-insurable risks given that insurance is less common in developing economies.
- ii) To carry out a rigorous statistical analysis into the detection of slowly evolving trends in climate extremes. Do these trends exist - in that they are statistically significant and what are the implications for future extremes in climate patterns? This research will also consider the co-dependence of climate variables such as temperature, precipitation and wind-storm, particularly in their extremes.
- iii) Apply robust decision theory to develop new pricing methods for financial and insurance instruments that are robust to uncertainty in the underlying process generating risks; notably catastrophe bonds and options and weather derivatives. We will also consider the design and implementation of robust mitigation policies such as carbon taxes which are insensitive to uncertainty in the underlying geo-physical processes.
- iv) The development and application of Robust Risk Management strategies with the objective of being able to provide forward looking assessments capable of quantifying the financial and insurance risks of catastrophic climate change and associated capital requirements. Robust pricing and risk management reflect the true costs created by uncertainty in global weather extremes and the ensuing capital requirements.
- v) Modelling and simulation:
  - a) To develop the financial sector of Warwick McKibbin's GCUBED model in order to be able to analyse the implications of global climate change for global financial markets and the simulation of robust mitigation policy and regulation.
  - b) Carry out simulations to develop probability measures for potential climate extremes using the geophysical models of climate change in collaboration with the Climate Research Unit and the Tyndall Centre for Climate Research, University of East Anglia.

**Objective:**

The underlying objective of the proposed research is to develop tools that will ensure the stability of global financial markets given the possibility that climate change induces an increased trend in extreme weather patterns. In this situation the greater risk bearing potential of financial markets implies that the insurance industry will need to exploit financial instruments and markets to obtain the required capital rather than rely on traditional methods of re-insurance. However the stochastic models of the underlying “weather asset” on which catastrophe options and weather derivatives are based are naïve and seriously deficient. .cf Standard & Poor’s (2005) -

“Over-reliance on catastrophe modelling may have compounded the losses faced by re-insurers in the wake of Hurricane Katrina, Those re-insurers who have placed heavy reliance on these models are likely to have under-priced catastrophe risk..... Katrina’s unexpected mix of wind and flood damage has reminded the industry that its experience, and therefore knowledge, of large loss events is limited. ..Catastrophe modelling, while to some extent a substitute for experience, has its limitations.”

We wish to undertake a rigorous statistical analysis of the joint dependence of climate extremes such as wind, temperature and precipitation and the question of evolving positive trends in these variables and their geographic concentration. Secondly, develop new pricing tools for catastrophe options, bonds and weather derivatives more generally using recent developments in robust decision theory. These robust methods are relatively insensitive to our lack of precise knowledge of the underlying geo-physical processes and will enable the market to recognise the true economic cost of such uncertainty in climate processes. Finally we wish to develop robust risk management strategies again using robust decision theory in conjunction with simulations carried out on Climate models from the University of East Anglia in order to simulate the impact of future weather scenarios on global financial markets.

Bringing climate change to the market, to enable it to be priced in an arbitrage free manner, as has been done with carbon trading, would seem to provide an important channel for the true economic costs to be realised. The research outlined below is fundamentally aimed at removing some of the barriers that would make this process possible.

### **Background:**

Specific events such as hurricane Andrew in 1992, the Northridge earthquake in 1994, the bombing of the World Trade Centre in 2001 and most recently the devastation caused by hurricane Katrina have all served to underline the increasingly stretched capacity of global insurance markets. At the time of its occurrence, hurricane Andrew was the largest since natural catastrophe (in terms of insured losses) and in its aftermath the insurance industry raised its capital levels, so that by the end of 1995 the primary and secondary (reinsurance) markets had access to around USD240 billion of capital which appeared to be more than sufficient to cope with Andrew's losses of \$21 billion. However, when put in context, the international financial markets had a capitalisation at that time of around USD19 trillion with an average daily volatility of approximately 70 basis points, or USD133 billion. Had a catastrophe such as Katrina – the final cost of which will be close on USD100 billion according to the latest ISO estimates – struck in 1995, it would have at stroke, wiped out nearly half of the capital of the insurance industry. Though the situation has improved slightly since then, a loss now of \$100 billion from Katrina will consume approximately 30% of the equity capital of the US insurance industry, but would be less than 0.5% of the value of the US stock and bond markets. Only two sources may be able to provide the capacity necessary to finance very large catastrophe risks – a government, with its power to tax, and the \$26 trillion capital market.

Government has been reluctant to take on additional catastrophe risk. But innovative insurers and financial engineers have developed ways of securitizing catastrophe risk to attract additional capital from investors. The question is how financial markets with such vastly greater risk bearing capacity could be used to hedge risk that has previously been covered using other channels. The market for Catastrophe Options and weather derivatives is relatively small and illiquid although it has grown. This growth is hindered by the fact that weather data is often poor and that pricing is based on naïve models of the underlying climate variables- typically autoregressive models or mean reverting diffusions (Hull-White) which run directly counter to apparent evidence that is accumulating that there are increasing trends in weather extremes.

## Specific Research Proposal:

i) **Assessing the current ability of financial markets to price and manage risks posed by global climate change.**

There is real concern within the insurance industry and financial markets that the true costs of climate change has not been fully recognised and hence valued. A report prepared for the Association of British Insurers in June of this year found that if it assumed a modest 6% increase in average hurricane wind speeds by 2080, based on IPCC data, excluding damage from storm surges, which caused most of Katrina's destruction, average annual wind damage costs alone would rise by 65% and insured losses from a single worst case hurricane would soar to around \$150bn. (economic loss is typically 3-4 times insured loss). The US Government Accountability Office provided a detailed assessment of the current and future capacity of both the insurance industry, financial markets and governments to cover natural catastrophic risk. The GAO report points out in stark terms the potential inability of insurance markets to bear the increasing costs of extreme events in both frequency and magnitude of impact.

There are human and non-human costs-non purely financial risks to consider as well as public health issues raised by increasing global temperatures. The research methodology for this part of the project will involve interviews, specific country analysis and the detailed analysis of financial flows following previous catastrophes.

Specifically the first phase of the project lasting 6 months will:-

1. Build on these two reports in order to synthesise information on the extent of potential liabilities and their geographical concentration. This exercise will extend the GAO and ABI reports in that they largely concentrated on the USA and UK and Europe respectively and insured risks. We have been given confidential access to the ISO catastrophe database in order to carry out this analysis.

2. To determine the degree of risk sharing globally and to understand the current inter-relationships between the insurance industry and financial markets. Standard & Poor's provides this information after specific events and we need to replicate this analysis. This will provide an analytical framework for the incorporation of a new financial structure into the GCUBED model.
3. To assess the barriers to the use of market based mechanisms for risk management and hedging and to assess the current usage of these instruments. This exercise will also consider the use of Weather Derivatives in a standard portfolio diversification strategy since they typically carry no market risk (temperature is for instance not an asset which is traded) and hence provides considerable potential in diversification.
4. To gather all relevant data required for subsequent analysis in the project.

ii) **Statistical detection of slowly evolving trends in climate extremes and climate co-dependencies**

The variability and the long-term trend of the processes from which climate extremes are generated appears to be changing. A study published by scientists from the Massachusetts Institute of Technology, in *Nature* in July 2005, found that the duration of cyclones and the highest wind speeds that they generated have increased by around 50% since the 1950s. The number of Category 4 and 5 hurricanes in the North Atlantic increased to 25 between 1990 and 2004 from 16 between 1975 and 1989.

1. We need to rigorously investigate the evidence, develop and apply statistical methods (Extreme Value Theory) that are specifically appropriate to address these issues. Professor Alexander McNeil is an expert in Extreme Value Theory and his expertise will be critical in this part of the project. He has

recently written papers on Self Exciting Extremes which are directly relevant to our study.

2. We also need to consider the Non-Gaussian dependence between climate variables in their extremes (simple correlation analysis between precipitation and temperature for instance fails to capture the correct measures of dependence as their joint density is Non-Gaussian) and conditional quantile analysis and dynamic copula analysis will provide the starting point for our research in this area and Professor Salmon and Dr. Dias are experts in this area along with Professor McNeil.
3. Given the lack of suitable statistical models for pricing Catastrophe options and weather derivatives this part of the project will also rigorously evaluate the standard models used in the market and develop new models based on the evolving EVT analysis outlined above.

iii) **The development of new financial instruments that are robust to uncertainty in the underlying risks**

Instability occurs in financial markets essentially because the flow of information has not been anticipated- a form of market failure. If there are no surprises there is little need for prices to move to clear the market. Pricing for extreme events that only occur with low probability is expensive and so the market relaxes and misvalues infrequent risks by essentially ignoring their existence. An optimal strategy would recognise the insurance component by explicitly recognising and including the valuation impact of the possibility of a rare risk into everyday strategies. When rare events subsequently occur, their impact would be then minimised because they had already been recognised and valued, with the costs incorporated into the premium paid.

As we have stressed above the underlying processes determining the evolution of climate variables is poorly understood in the markets and hence there is “model risk” created through the use of misspecified models which in turn implies the mispricing of extreme risks in particular. Standard option methods do not work as the underlying variable, say temperature is not traded-“you can’t buy a sunny day”.

The development of robust control theory (see Hansen and Sargent (2006) for an introduction to Economic applications of this theory) over the last ten to twenty years, however, opens the possibility to design pricing methods that are relatively insensitive to model misspecification and hence price uncertainty as opposed to risk. In essence these robust methods construct the best solution in the face of a set of potential models of the environment rather than a single model that is traditionally used. This can imply a form of minimax strategy in which the best policy is the one that minimises the loss given that the worst environment is thrown at you from within a specified set of environments. Current valuation methodologies for such instruments used in financial markets are known to fail to recognise the misspecification of the underlying stochastic process generating the risks and hence the application of standard delta and gamma hedges provide extremely poor performance. A completely new approach is required and the robust optimal control literature can be applied here with relative ease

1. We propose to develop robust option pricing and hedging instruments using Robust Lyapunov methods to stabilise financial and insurance markets in the face of extreme and uncertain risks (see Freeman and Kokotovic, 1996). Dr. Weston has recently completed his thesis in this area and his participation is central to this part of the research programme.
2. We also wish to develop methods that allow for state dependent preferences for robustness or uncertainty aversion. The extreme solution in this case need not then be so extreme that insurance is completely withdrawn from the market or the implied weather derivative so expensive that there will be no liquidity at all.
3. We will also explore the analysis of robust mitigation policy in the face of climate change. At the microeconomic level trading in carbon emissions is a rapidly growing activity; at the macroeconomic level, carbon based taxes need to be designed that recognise and hence are robust to the uncertainty and misspecification in the underlying geophysical processes. A second and ancillary element of the project would then be to develop robust carbon tax policies and to compare their performance in the face of alternative climate scenarios. Similar research has recently been carried

out in the area of robust monetary policy (See special issue of Macroeconomic Dynamics on Robust Policy, Feb 2002 edited by Mark Salmon)

**iv) Robust Risk Management**

The two preceding sections have outlined the basic technical tools we need to address the analysis of the financial implications of climate change; the statistical model that describes the underlying process and then how to price financial instruments in the face of the inevitable uncertainty or misspecification in these models. The next stage is to consider how to best manage and monitor environmental risk within financial markets.

Consistent with the view outlined above we will consider the problem of managing uncertainty as a minimax problem, on the grounds that decisions under uncertainty are incorrectly based on expected value optimisation which will never be robust since it ignores the possible impact of the uncertainty in the distribution over which the expected value is taken- the model risk.

Therefore, if the objective is to manage risks that are robust in the face of the worst-case outcome, the appropriate course of action is then to adopt the minimax criteria as the decision metric. There is a real need to construct risk management strategies that can simultaneously satisfy both stability and robustness criteria, whilst still being optimal with respect to meaningful profit/loss functions.

1. We intend to develop this form of risk management analysis using the underlying model of risks identified in section ii) above as the nominal model in the set of models we seek to be robust against together with the implementation of standard- non robust pricing as well as robust pricing as described under iii). This provides the range of models and hence the distribution to capture the model risk to be combined with market risk in VaR or expected shortfall analysis, where again a copula combines these two risk distributions.
2. An added aspect is that catastrophic environmental events have been shown to exhibit highly non-linear dynamics. The approach to tackling these

complexities implies the use of non-linear robust optimal control theory through the Lyapunov function approach to accommodate the non-linear dynamics and then to construct risk management strategies that are based on entire classes of cost functions that are meaningful across a wide range of potential extreme loss events.

v) **Modelling and Simulation**

We need to use two modelling frameworks; the first focuses on Economics but lacks a detailed financial sector, McKibbin's GCUBED model and secondly a Geo-Physical model developed by the Climate Research Unit at the University of East Anglia in order to develop a range of scenarios regarding potential global weather extremes and to simulate the impact of the introduction of Robust Financial Instruments as described above.

a. **Develop the financial sector of Warwick McKibbin's global GCUBE model so that global financial flows and risk sharing can be analysed.**

We need a tool to evaluate the impact of global climate change specifically on financial and insurance markets. By far the best tool that exists is the model developed by Professor Warwick McKibbin from the Australian National University. This model has been used to analyse the Kyoto protocol and alternatives such as the McKibbin-Wlicoxen Blueprint. However it does not have a detailed breakdown of financial and insurance markets and we will need to extend this model in order to be able to analyse the financial impact of climate change and its sectoral and geographical impacts. Professor McKibbin has agreed to act as a consultant to this project and we can see a clear need for interaction between his team and our own. Much of this can be electronic but we will also require a number of face to face meetings, hence the need for additional travel and subsistence expenses between Warwick and Canberra.

**b. Carry out simulations and develop potential scenarios and probability assessments using the geophysical models of climate change in collaboration with the Climate Research Unit, University of East Anglia**

We need to develop probability distributions to assess future climate risks and two methods are proposed in this project. The first described above rests on the proper statistical detection of evolving extremes and the second will exploit the world leading experience and models of the Climate Research Unit and the Tyndall Centre for Climate Change at the University of East Anglia. These models provide the critical geophysical information we need to feed into the extreme and risk analysis and the GCUBED model to assess the impact on financial markets and the global economy more widely. Professor Nigel Arnell and Dr. Tim Osborne are essential consultants to the project at this stage, Dr. Rachel Warren, will be integrated from the outset in the entire programme of research.

The **Community Integrated Assessment Model, CIAS** will be installed at Warwick Business school to enable the project to access the suite of Climate models available within this framework.. We shall specifically exploit several components of this system:

*The Emission Scenario Module, ESM,*

The ESM model is simply a database and contains a list of scenarios for CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, SO<sub>2</sub>, CFCs and PFCs.

*Climate Model Component 1: MAGICC*

The simple climate model, MAGICC, was used to illuminate the consequences of the SRES scenarios in the IPCC Third Assessment Report (IPCC 2001). The MAGICC model has been developed and updated over 2 decades. The package allows the user to determine changes in CO<sub>2</sub> concentration, global mean surface air temperature and sea-level between the years 1990 and 2100 resulting from anthropogenic emissions of CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>), HFCs, CFCs and PFCs, as well as SO<sub>2</sub>.

*ClimGen: a spatial climate scenario generator*

Spatially-resolved climate scenarios will be obtained using ClimGen which provides high-resolution data over the global land surface on a 0.5° latitude by 0.5° longitude grid, on either monthly, seasonal or annual timescales, time series from 2000 to 2100 in terms of mean temperature, extreme flood distributions, annual average global temperature rise and sea level rise.

**Expected Outputs**

We intend to publish regular reports as the research progresses and submit these papers to the leading academic journals. We will run two workshops each year in Environmental Finance in London in order to stimulate interest in the area. A single “Environmental Finance” conference is planned for the end of the research programme. We would seek industry support for these events.

**Justification of Resources**

A post doctoral research fellow will carry out the majority of the work on this project and will require a desktop computer, laptop and printer in order to be able to present the results from the project internationally; the climate models are highly computer intensive. We request funds to enable the collaboration between the consultants and personnel at Warwick as well as Warwick personnel travelling to London, Norwich as well as internationally to present the results of this research to a wider academic community. Secretarial support at one tenth is required to coordinate the project.

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