Author details:

Pauline Barrieu

Statistics department

London School of Economics

Houghton Street

London WC2A 2AE

United Kingdom

tel: +44 207 955 6016

fax: +44 207 955 7416

p.m.barrieu@lse.ac.uk

Olivier Scaillet

Swiss Finance Institute and HEC Genève

UNI MAIL

Bd Carl Vogt 102

CH - 1211 Genève 4 Suisse

tel. ++ 41 22 379 88 16 (direct)

++ 41 22 379 81 03 (HEC)

fax ++ 41 22 379 81 04

scaillet@hec.unige.ch

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2. Contributor Names: Pauline Barrieu / Olivier Scaillet

3. Basic contributor affiliations: London School of Economics / Swiss Finance Institute and HEC University of Geneva

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Weather is not only an environmental issue but also a key economic factor, as recognized by the former US Commerce Secretary, William Daley, in 1998, when he stated that at least USD 1 trillion of the world economy is weather sensitive. The risk exposure is not homogeneous across the globe and some countries, usually those heavily dependent on agriculture, are more sensitive than others. It also includes a large range of phenomenons such as modifications in temperature, wind, rainfall or snowfall.

Weather risk has some specificities compared to other sources of economic risk: in particular, it is a local geographical risk, which cannot be controlled. The impact of weather is also very predictable: the same causes will always lead to the same effects. Moreover, weather risk is often referred to as a volumetric risk, its potential impacts being mainly on the volume and not (at least directly) on the price. This explains why hedging of weather risk via the trading of commodities futures is difficult and imperfect. For example oil futures price does not depend solely on demand (cold winter) and can be high even if demand is low in case of a war for instance. Volumetric risk is imprecisely compensated by the price variation in the futures position.

Usually, when subject to some risk, it is possible to hedge against it by contracting some insurance policies. But, this is not really a possibility for weather risk for two main reasons: first it is more a high frequency - low severity risk but also the same weather event can generate economic losses for some agents and some gains for others. To deal with this risk, some financial contracts depending on weather conditions (temperature, rainfall, snowfall...) were created and introduced on the financial market 10 years ago. They are called weather derivatives.

WEATHER DERIVATIVES

Weather derivatives are financial instruments whose value and/or cash flows depend on the occurrence of some meteorological events, which are easily measurable, independently authentifiable, and sufficiently transparent to act as triggering underlyings for financial contracts. Typically location is clearly identified and measurement is provided by independent and reliable sources. The underlying meteorological events can be considered as noncatastrophic.

According to the Weather Risk Management Association (WRMA), the financial market related to weather has two main facets: the management of the financial consequences of adverse weather for those with natural exposure to weather, and the commercial trading of weather risk, both in its own right and in conjunction with a variety of commodities.

The first weather transactions took place in 1997 between Enron and Koch Industries. These transactions were the result of a long thinking process by Koch, Willis and Enron aimed at finding a means of transferring the risk of adverse weather. These deals followed the deregulation of the energy market in the US (transition from an oligopolistic position to a status of mere participant to a competitive market) and were based upon some temperature indices to compensate the energy producer in case of a mild winter.

The most common underlying is related to the notion of Degree Day which is expressed as the difference between a reference level temperature (65^oF or 18^oC) and the average daily temperature T. The average is computed between the maximum and minimum recorded temperature over a particular day. A Heating Degree Day (HDD) is defined as follows: HDD $= (65^oF-T)^+$, where $(.)^+ = \max(.\,,0)$. The bigger the HDD is, the colder the temperature is, and as a consequence the larger the demand for heating will be. Similarly a Cooling Degree Day (CDD) is defined as follows: CDD $= (T-65^oF)^+$.

The definition of a temperature index in those terms reflects the close relationship between the energy sector and the weather derivative market. Daily results are often cumulated to give a total on a given period, such as a week (Xmas-NewYearEve, sport event), a month (sales period, harvest period), or a quarter (summer holidays, opening season of a resort).

THE WEATHER DERIVATIVES MARKET

Most of the transactions are tailor-made and part of the OTC (Over The Counter) market. Usually OTC transactions are realized within the ISDA standards (Master Agreement standards of the International Swap and Derivatives Association) which provide standardised contracts aimed at easing OTC transaction processes. Some go through specialized brokers but most of them are done without any intermediaries. Taylor-making is not surprising as these structures suit better the management of weather risk and the needs of the various players on this market. The organized markets are however rather successful, mainly because of the transparency, liquidity and security they offer. Among them, the most predominant one is the Chicago Mercantile Exchange (CME), who offers several types of contracts.

Some attempts were made in Europe to launch an independent organized market for weather derivatives. In November 2005, Powernext, which is a European energy exchange based in France, and Meteo France launched the quotation of national temperature indices for 9 European countries and different types of indices. This initiative is further developed with the launch in June 2007 of Metnext, specialized in indices for weather risk management. Meteo-France and Euronext, a subsidiary of NYSE Euronext, have teamed up to launch a joint venture named Metnext specializing in innovative solutions for index-based management of weather risk.

Beside organized markets, and this since the beginning of the weather market in the late 90s, electronic trading platforms have always played an important role in the development of the market, especially Enron's platform in the early days. A lot of big market players have such a platform, and in particular Spectron is rather important in Europe.

MICROINSURANCE AND WEATHER DERIVATIVES

One of the most spectacular developments of weather derivatives lies however upon the specificities of this widespread risk, with among the most exposed those relying on agriculture. Microinsurance, i.e. a microfinance service that allows poor individuals to insure possessions, such as livestock or crops, has soon be seen as a fantastic potentiality offered by weather derivatives. Therefore, it seems natural to see the World Bank as one of the actors on this market. Among the various structures of the World Bank, the International Force on Commodity Risk Management (CRM, [4]) has for main objective to deal with the agricultural risk in developing countries, where agricultural risk is defined as "negative outcomes stemming from imperfectly predictable biological, climatic and price variables". The economic and social consequences of this risk being so huge in some countries, it seems logical to seek for some form of protection against this risk. However, even if insurance companies were to write insurance policies against this risk, they would be typically too expensive for small farmers, and the compensation would take too long to be effective, partly because of the claim checking procedure. The CRM has developed several projects throughout the globe in order to deal with agricultural risk transfer using weather derivatives. Among these projects, the pilot program conducted in India between 2003 and 2006 has been particularly successful. Microinsurance is a growing sector and more and more projects have been conducted across the globe to protect small and medium size farmers from weather risk. Some reinsurance companies have been particularly active in these programs helping local institutions to implement the insurance schemes.

PRICING OF WEATHER DERIVATIVES

Given the uncertainty and the flexibility in their accounting classification, but also their relative illiquidity, several pricing methods have been suggested for weather derivatives. They can be classified into three main categories: actuarial, financial and economic. In the following, we will briefly present these various approaches, focusing on the (forward) pricing rule of a weather derivative with a payoff H at a future time. Considering forward price allows us to simplify the problem in terms of interest rates and to focus on the pricing rule itself.

The actuarial method uses the fair value, corrected by some margin as pricing rule. More precisely, denoting by P the statistical probability measure used as prior probability measure, the (forward) price of the derivative can be obtained as $\pi(H) = E_P[H] + \lambda\sigma_P[H]$. Different authors have studied the impact of the choice of the probability measure on the pricing (see e.g. [9], [10]).

The financial method often assume the weather derivative market to be complete and therefore use the risk-neutral pricing rule $\pi(H) = E_Q[H]$ where the expectation is taken under a unique martingale measure Q. A milder argument consists in assuming absence of arbitrage opportunities only. In an incomplete market framework, there exist many different methods to price a contingent claim, without creating any arbitrage opportunity. A rather standard approach involves utility maximization. Any individual wants to maximize the expected utility of her terminal wealth in this framework. The maximum price she is ready to pay for the weather derivative is therefore the price such that she is indifferent, from her utility point of view, between buying it or not buying it. For this reason, the price obtained by utility maximization techniques is called indifference price (many references exist on this subject, e.g. [7]).

Denoting by u the utility function of the agent we consider, and assuming that there is no interest rates (for the sake of simplicity), the indifference buyer price of H, $\pi^b(H)$ is determined as $E_P[u(W_0 + H - \pi^b[H])] = E_P[u(W_0)]$, where W_0 is the initial wealth (which may be random). The price $\pi^b(H)$, which theoretically depends on the initial wealth and on the utility function, is not (necessarily) the price at which the transaction will take place. This gives an upper bound to the price the agent is ready to pay for the payoff *H*. The agent will accept to buy the contract at any price below $\pi^b(H)$. In the characterization of the indifference price, there is no question on the volume of the transaction. The potential buyer has two options: either buying 1 contract or not buying it. There is another possible approach, which consists of determining the price of the contract such that agreeing a little into the contract has a neutral effect on the expected utility of the agent. This notion of fair price in that context was first introduced by Davis in [5] and [6] and corresponds to the zero marginal rate of substitution price. More precisely, the fair price *p* is determined such that $\frac{\partial E_P[u(W_0 + \theta H - p)]}{\partial \theta}\Big|_{\theta=0} = 0$.

Finally the economic approach relies on a transaction price, which is an equilibrium price, either between the seller and the buyer only, or between the different players in the market. Note that a transaction will take place only if the indifference buyer price is higher than the indifference seller's price, which gives a lower bound to the price the seller is ready to accept for the contract. This is a necessary condition for a transaction, and more generally for a market equilibrium, which characterizes the situation where all agents in the market maximize their expected utility at the same time by exchanging their risks (such an equilibrium is also called Pareto-optimal). Such an equilibrium approach has been adopted by different authors, such as [3] or [9]. While the first authors look at how weather forecasts can influence the demand for weather derivatives, and hence their price, the latter consider the problem of pricing in an incomplete market, with a finite number of agents willing to exchange their weather risk exposure. The price of the contract is obtained as that of the Pareto-optimal equilibrium.

DESIGN ISSUES

As shown by various failed attempts of weather risk securitization, in particular the failed issued of a weather bond by Enron in 1999 (see [1] or [2] for a detailed study), the design of the new securities appears as an extremely important feature in the transaction. It may be the difference between success and failure. More precisely, as previously mentioned, the high level of illiquidity, deriving partly from the fact that the underlying asset is not traded on financial markets, makes these new products difficult to evaluate and to use. The characterization of their price is very interesting as it questions the logic of these contracts itself. Moreover, the determination of the contract structure is a problem in itself: on the one hand, the underlying market related to these risks is extremely illiquid, but on the other hand, the logic of these products itself is closer to that of an insurance policy. Consequently the question of the product design, unusual in finance, is raised.

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