1

Weather derivatives and the weather derivatives market

1.1 Introduction

This book is about the valuation of a certain class of financial contracts known as weather derivatives. The purpose of weather derivatives is to allow businesses and other organisations to insure themselves against fluctuations in the weather. For example, they allow natural gas companies to avoid the negative impact of a mild winter when no one turns on the heating, they allow construction companies to avoid the losses due to a period of rain when construction workers cannot work outside and they allow ski resorts to make up for the money they lose when there is no snow.

The weather derivatives market, in which contracts that provide this kind of insurance are traded, first appeared in the US energy industry in 1996 and 1997. Companies accustomed to trading contracts based on electricity and gas prices in order to hedge their electricity and gas price risk realised they could trade contracts based on the weather and hedge their weather risk in the same way. The market grew rapidly and soon expanded to other industries and to Europe and Japan. Volatility in the financial markets has meant that not all of the original participants are still trading, but the weather derivatives market has steadily grown and there are now a number of energy companies, insurance companies, reinsurance companies, banks and hedge funds that have groups dedicated purely to the business of buying and selling weather derivatives. The Weather Risk Management Association (WRMA), the industry body that represents the weather market, recently reported a total notional value of over $10 billion for weather derivative trades in the year 2002/2003.[1]

During the eight years since the first weather derivative trades took place the 'science' of weather derivative pricing has gradually developed. It now

[1] See http://wrma.org.

seems possible, and – hopefully – useful, to bring this information together into one place, both for the benefit of those already involved in the market as a point of reference and for those outside the market who are interested to learn what weather derivative pricing is all about. Other than this chapter, which contains introductory material about weather derivatives and the weather derivative market, the book focuses on the meteorological, statistical, mathematical and financial issues that determine the methods used for the pricing, valuation and risk management of weather derivatives contracts and portfolios. We attempt to describe all the methods and models currently in use in the weather market and give examples of how they can be applied in practice. We cannot cover everything, however. There are many ways of approaching the question of how to price a weather derivative, there are strong financial incentives to invent (and keep secret!) new and more accurate methods for such pricing, and there is undoubtedly much progress still to be made.

The overall level of this book is such that a technical graduate with a reasonable understanding of mathematics should be able to follow almost all of it, and no particular background in meteorology, statistics, mathematics or finance is required. We hope that, if you read this book, you will learn something of each of these subjects.

This chapter proceeds with a brief introduction to the weather derivatives market, a description of the various weather indices used by the market, a description of how these weather indices are related to the pay-offs of weather derivative contracts, and an overview of the methods used for the valuation of weather contracts.

1.1.1 The impact of weather on business and the rationale for hedging

The types of impact of weather on businesses range from small reductions in revenues, as might occur when a shop attracts fewer customers on a rainy day, to total disaster, such as when a tornado destroys a factory. Tornadoes are an example of what we will call *catastrophic* weather events. Such weather events also include severe tropical cyclones, extra-tropical wind storms, hail storms, ice storms and rain storms. They often cause extreme damage to property and loss of life. Companies wishing to protect themselves against the financial impact of such disasters can buy insurance that will pay them according to the losses they sustain. Weather derivatives, however, are designed to help companies insure themselves against *non-catastrophic* weather events. Non-catastrophic weather fluctuations include warm or cold periods, rainy or dry periods, windy or calm periods, and so on. They are expected to occur reasonably frequently. Nevertheless, they can cause significant discomfort for (or bring significant benefits to) businesses with profits that depend in a sensitive way on the weather. Hedging with weather derivatives is desirable for such businesses because it significantly reduces the year-to-year volatility of their profits. This is beneficial for a number of reasons, including:

- low volatility in profits can often reduce the interest rate at which companies borrow money;
- in a publicly traded company low volatility in profits usually translates into low volatility in the share price, and less volatile shares are valued more highly;
- low volatility in profits reduces the risk of bankruptcy.

Although a company hedging its weather risk using weather derivatives will typically lose money, on average, on the hedge, it can still be very beneficial to hedge for these reasons.

Governmental and non-profit use of weather derivatives

Weather derivatives can also be used by non-business entities, such as local and national government organisations and charities. In these cases it would typically be weather-induced fluctuations in costs that would be hedged. Such hedging can reduce the variability of costs from season to season or year to year, and hence reduce the risk of unexpected budget overruns.

1.1.2 Examples of weather hedging

Weather variability affects different entities in different ways. In many businesses weather is related to the volume of sales transacted. Examples of this would include:

- a natural gas supply company, which would sell less gas in a warm winter;
- a ski resort, which would attract fewer skiers when there is little snow;
- a clothes retailing company, which would sell fewer clothes in a cold summer;
- an amusement park, which would attract fewer visitors when it rains.

But weather can also affect profits in ways other than through changes in the volume of sales. Examples include:

- a construction company, which experiences delays when it is cold or raining because labourers cannot work outside;
- a hydroelectric power generation company, which generates less electricity when rainfall is reduced;

- a vehicle breakdown rescue company, which has increased costs on icy days, when more traffic accidents occur;
- a fish farm, where fish grow less quickly when the sea temperature is lower.

All these risks could be hedged using weather derivatives.

1.1.3 The definition of a weather derivative

A standard weather derivative contract, as might be used to hedge the risks described above, is defined by the following attributes:

- the contract period: a start date and an end date;
- a measurement station;
- a weather variable, measured at the measurement station, over the contract period;
- an index, which aggregates the weather variable over the contract period in some way;
- a pay-off function, which converts the index into the cashflow that settles the derivative shortly after the end of the contract period;
- for some kinds of contract, a premium paid from the buyer to the seller at the start of the contract.

These basic attributes are supplemented by:

- a measurement agency, responsible for measuring the weather variable;
- a settlement agent, responsible for producing the final values of the index on the basis of the measured values; according to defined algorithms that (hopefully) cope with all eventualities, such as a failure of the measuring equipment;
- a back-up station, to be used in case the main station fails;
- a time period over which the settlement takes place.

It is not the purpose of this book to describe the legal and administrative aspects of weather derivatives, although these are, clearly, of vital importance for companies trading these contracts. Rather, we intend to investigate the methods that can be used to set reasonable prices for and assess the value of the various types of contracts available in the market today.

1.1.4 Insurance and derivatives

Weather derivatives have a pay-off that depends on a weather index that has been carefully chosen to represent the weather conditions against which protection is being sought. The economic effect of hedging using weather derivatives can also be achieved using an *insurance* contract that has a pay-off based on a weather index. Nevertheless, we will use the phrase weather *derivatives* throughout this book, although all the analysis presented applies equally well to both types of contract.

There are some differences between weather derivatives and index-based weather insurance that may mean that one is preferable to the other in certain circumstances. Some companies may not be happy with the idea of trading derivatives but comfortable with buying insurance, for instance.

Other ways in which insurance and derivatives differ include the following:

- it may be necessary to perform a frequent (daily, weekly or monthly) revaluation of derivative positions, known as mark to market or mark to model, but this is usually not necessary for insurance;
- tax liabilities may be different (most commonly, insurance incurs a tax but derivatives do not);
- the accounting treatment may be different;
- contractual details may be different.

All of these vary to a certain extent from country to country.

Indemnity-based weather insurance

There is also a kind of weather insurance in which the pay-off is related to financial loss rather than to a weather index. Such contracts are less suitable for the hedging of weather-related fluctuations in profits, because a lack of profit cannot necessarily be classified as a weather-induced loss. The modelling and pricing of these contracts are rather more complicated than those of weather derivatives, since they involve understanding the relationships between weather and loss, and the likelihood that the insured entity will make a claim. Such pricing is more akin to the pricing of catastrophe-related weather insurance (Woo, 1999) and is not covered in this book, although the analysis we present does form a good first step towards the pricing of such contracts in some cases.

1.1.5 Liquidity and basis risk

Because the pay-off of a weather derivative depends on a weather index, not on the actual amount of money lost due to weather, it is unlikely that the pay-off will compensate exactly for the money lost. The potential for such a difference is known as *basis risk*. In general, basis risk is smallest when the financial loss is highly correlated with the weather, and when contracts of the optimum size and structure, based on the optimum location, are used for hedging.

For a company deciding how to hedge its risk there is often a trade-off between basis risk and the price of the weather hedge. Weather contracts on standard indices on London, Chicago and New York temperatures are traded frequently, and consequently it is usually easy to trade such contracts at a good price. However, except in lucky cases, it is unlikely that such contracts will minimise basis risk for the hedging company. Hedgers then have a choice between, on the one hand, getting the best price but trading a contract that may not hedge their business particularly well and, on the other hand, hedging their business as well as possible but not necessarily getting such a good price.

1.1.6 Hedgers and speculators, primary and secondary markets

Every weather derivative is a transaction between two parties. We will classify all such parties as being either *hedgers*, who have weather risk they want to reduce or eliminate, or *speculators*, who are making a business by writing weather contracts. This separation of all traders of weather derivatives into hedgers and speculators is useful, but is also a simplification of reality. For instance, many hedgers also trade speculatively, partly in order to ensure that they understand the market before they buy a hedge, partly to disguise their hedging intentions to other traders and partly just to try and make money. Similarly, speculators may become hedgers if they decide that their speculative trading has led them to a position where they hold too much risk.

Transactions between hedgers and speculators are referred to as the primary market, while transactions between speculators and other speculators are known as the secondary market. The speculators trade contracts with each other either because they want to reduce the weather risk they have that arises from holding previously traded weather derivatives (in which case, they are also becoming hedgers), or simply because they think they can make money by doing so.

Very occasionally contracts are exchanged directly between two hedgers, who, by doing so, can hedge each other's risks simultaneously. However, this is extremely uncommon, since it is rare for two companies to have exactly equal and opposite weather risks.

From the point of view of the speculator, who may be a bank, insurance company, reinsurance company, energy company or hedge fund, trading weather derivatives forms an attractive proposition for two reasons. First, weather derivative pay-offs are generally uncorrelated with other forms of insurance or investment. As a result of this an insurance company can issue weather derivatives cheaply relative to other forms of insurance because the overall company risk will increase less. Similarly, a hedge fund can invest in weather derivatives knowing that their return is uncorrelated with the return on the other financial assets it may hold, such as equities and bonds.

Second, a portfolio of weather derivatives can, in itself, be very low risk because of the potentially offsetting nature of weather contracts. An ideal weather market would be driven by businesses that are, in aggregate, seeking to hedge against equal and opposite amounts of each weather risk. In principle this could lead to a situation in which the speculators hold very little risk because they would simply be middlemen passing weather risk from one hedger to another. The risk would be exchanged almost at cost price, with little or no risk premium.

1.1.7 Over-the-counter and exchange trading

There are a number of ways in which a weather derivative trade can take place. Primary market trades are usually ‘over the counter’ (OTC), meaning that they are traded privately between the two counterparties. Much of the secondary market is traded through voice-brokers, who act as intermediaries and cajole participants in the market to do deals, but do not actually trade themselves. These trades are also described as OTC. Finally, a growing part of the secondary market is traded on the Chicago Mercantile Exchange (CME), which currently lists weather derivatives for fifteen US, five European and two Japanese locations based on temperatures for each month of the year. The CME plays the dual roles of bringing transparency (the prices are freely available on the Internet) and eliminating credit risk (since you trade with the CME rather than with the other counterparty, and make margin payments on a daily basis).

Secondary trading and the Pareto optimum

Trading between speculators in the secondary market may, at first look, appear to be a zero-sum game, and have little net economic benefit. This may be the case with certain trades, but is not the case in general. A secondary market trade can quite conceivably reduce the risk of both parties to the trade, or at least reduce the total risk held by the two parties (i.e. the risk decrease on one side is greater than the risk increase on the other). And the lower the risk held by parties in the secondary market, the lower the premiums that can be charged to hedgers. In this way, it is in both hedgers’ and speculators’ interest for secondary trading to occur until an optimum situation has been achieved in which the total risk held by the players in the secondary market is the least. Reaching such a situation may take many secondary market trades, even in a market with only a few players, and this is reflected in the fact that there are typically many more secondary market trades than primary market trades.

Mathematical models of this idea have been studied by economists. When considered in terms of economic utility, secondary market trading is certainly not a zero-sum game, and one can idealise secondary trading as moving the entire market towards the situation where the total expected utility of the participants is the greatest possible. This is known as the Pareto optimum.

1.1.8 Hedging and forecasts

At this point the reader may be wondering about the relationship between the hedging of weather risk and the use of weather forecasts. Meteorological forecasts contain information about the weather a few days in advance (in the case of weather forecasts) or a few months in advance (in the case of seasonal forecasts). For certain business decisions, especially those on timescales of a few days, such forecasts can be very useful. The appropriate use of forecasts can both increase the expected profits *and* reduce the risk of making a loss, while weather derivatives, in most cases, only reduce the risk of making a loss. However, a company making plans for the month, quarter or year ahead cannot make much use of forecasts. Weather derivatives, on the other hand, are ideally suited to all periods in the future. Meteorological forecasts and weather derivatives are thus perfect complements: what can be predicted with accuracy should be, and action should be taken on the basis of such predictions. Everything else can be hedged.

There are also two ways in which weather derivatives can be used to enhance the usefulness of weather forecasts. One is that a forecast can be used to determine the best course of action, and a weather derivative can hedge against the possibility that the forecast is wrong. The derivative would pay out according to the size, and possibly direction, of the forecast error. For example, consider a supermarket that buys certain perishable fruits and vegetables on short notice according to the weather forecast. If the forecast is wrong and the supermarket sells less than predicted it will lose revenue relative to the situation in which the forecast is correct. This revenue at risk could be hedged using a weather derivative that pays according to the forecast error.

The other way that weather derivatives can be used to enhance forecasts is that a forecast can be used to determine the course of action, and a weather derivative can hedge against the occurrence of forecasts that lead to a high cost being incurred. An example of this might be an oil platform in the Gulf of Mexico that evacuates staff when there is a hurricane forecast. A weather derivative could be structured to cover the cost of such an evacuation. Interestingly, in this case the actual weather does not influence the pay-out of the contract, only the forecast.

A final aspect of the relationship between meteorological forecasts and weather derivatives is that forecasts play a major role in the valuation of weather derivatives in certain circumstances. This is addressed in detail in chapter 10.

1.1.9 Hedging weather and price

The situation often arises that a company is exposed to both weather and the price of some commodity in a connected way. Consider a company that has to buy more natural gas when it is cold. If the gas is being bought at a fixed price, then this purchase involves only weather risk. The total cost of the gas bought is given by

$$\text{cost} = P_0 V \tag{1.1}$$

where P_0 is the fixed price and V is the weather-dependent amount of gas.

But if the gas is being bought at a varying price then the company is exposed not only to the weather but also to fluctuations in that price. The total cost is now given by

$$\text{cost} = PV \tag{1.2}$$

where P also varies. One can say that the level of weather risk depends on the gas price, or that the level of gas price risk depends on the weather. In some cases the variability of the weather and the gas price may be independent, which simplifies the analysis of these situations. However, often the changes in the gas price are partly affected by the weather as well (since cold weather increases demand for gas, which in turn increases the price). Hedging combined weather and price risk is more complex than hedging straightforward weather risk or price risk alone, and ideally involves contracts that depend on both the weather and the price. Only a few contracts of this type have been traded to date. The pricing of such contracts is discussed briefly in chapter 11.

1.2 Weather variables and indices

As we have seen, weather affects different entities in different ways. In order to hedge these different types of risk, weather derivatives are based on a variety of different weather variables and can also be structured to depend on more than one weather variable. The most commonly used weather variable is the temperature, as either hourly values, daily minima or maxima, or daily averages. Of these, daily average is the most frequently seen. In most countries daily average is defined by convention as the midpoint of the daily minimum and maximum. However, in some countries daily average is defined as a weighted average of more than two values of temperature per day. Definitions based on three, twelve, twenty-four or more values per day are all in use. The exact time period over which the minimum and maximum temperature are measured, and exactly how minimum and maximum are defined, also vary from country to country. To participate in the weather market one has to do thorough research into the weather measurement conventions in use in each country in which one operates.

As an example of minimum and maximum temperature values, figure 1.1 shows daily minimum, maximum and average temperatures measured at London's Heathrow Airport for the year 2000.

In addition to temperature, wind and precipitation measurements are also used as the weather variables underlying weather derivatives. Wind-based hedges are, for instance, of interest to wind farms, which want protection

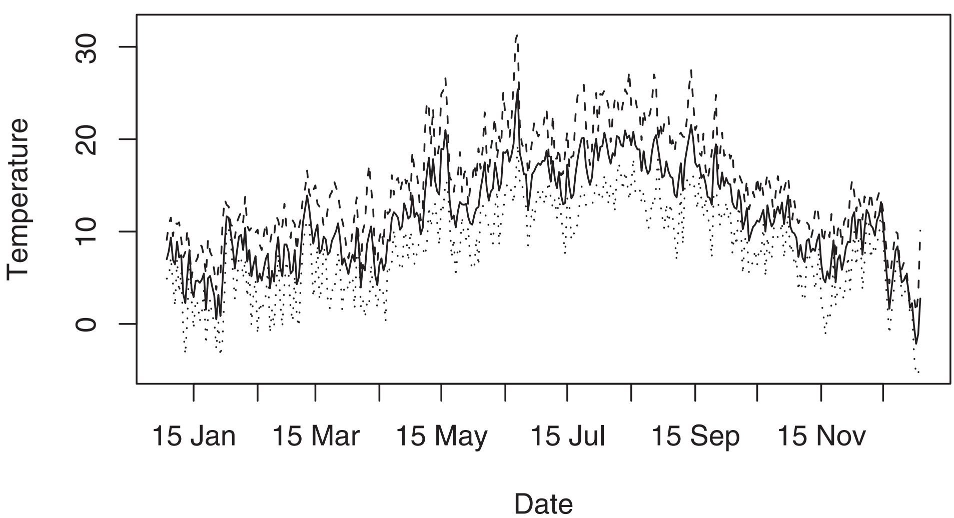

Figure 1.1. Daily minimum (dotted line), maximum (dashed line) and average (solid line) temperatures for London Heathrow, 2000.