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Modeling and Pricing Weather-Related Risk

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Preface

In the last decade, a new category of financial derivatives was developed, namely, weather derivatives. These financial products were developed by energy and utility companies as an effective tool for hedging the volumetric risk of the energy units sold, rather than the price risk of each unit. Weather derivatives are financial instruments that can be used in order to reduce risk associated with adverse or unexpected weather conditions. The payoff of a weather derivative depends upon the index of an underlying weather measure such as rainfall, temperature, humidity, or snowfall. In contrast to the classical financial markets, the weather market is incomplete in the sense that the underlying assets cannot be stored or traded.

The weather market is one of the fastest developing markets. However, many investors are hesitant to actively enter the market. The main reasons are the difficulty in pricing the traded financial products as well as the difficulty in accurately modeling the underlying weather variables. In addition, the number of publications arising from the academic community is limited. Finally, most investors lack the knowledge of the existence of the weather market and the benefits that it can provide.

The aim of this book is to provide a concise and rigorous treatment of the stochastic modeling of weather market as well as to significantly contribute to the existing literature. Presenting a pricing and modeling approach for weather derivatives written on various underlying weather variables will help investors and companies to accurately price weather derivatives and will help them to effectively hedge against weather risk.

First, the basic aspects of the weather market are discussed. More precisely, we discuss about the purpose of weather derivatives and the history of the weather market, we present the investors of this market, and we point out the differences between weather derivatives and insurance as well as the main problems of the market. Next, we discuss methods for data preprocessing. More analytically, methods for cleaning the data as well as identifying and model trends, jumps, and discontinuities are presented. Third, we present the available modeling and pricing methodologies of weather derivatives. Understanding the weaknesses and advantages of each method will help us build a model that accurately describes the dynamics of the weather variables. Fourth, linear and nonlinear, nonparametric methods are presented in modeling temperature wind and precipitation. Fifth, the models that developed for the weather variables are used in order to provide analytical pricing formulas for the various securities that are traded in the weather market. Next, we discuss how our modeling and pricing methodologies can be improved using meteorological forecasts. Finally, the notion of basis risk is explained and discussed. In the sense of weather derivatives, basis risk has two components arising from both the choice of weather station where a derivative contract is written, as well as the relationship between the hedged volume and the underlying weather index.

We tried to make the material accessible and readable without excessive mathematical requirements, for example, at a level of advanced MBA or Ph.D. students and industry professionals with a background in financial econometrics. Moreover, there is an introduction – tutorial – to data preprocessing to acquaint non-statisticians to the basic principles and a similar but more extensive introduction to stochastic calculus for scientists of non-finance area, firstly introducing the basic theorems and gradually building up to more complex frameworks. This introductory chapter to stochastic calculus will present all the necessary material to the reader to help him understand and follow the sections about the pricing of the weather derivatives.

Familiarity with the operations of the capital markets will help (e.g., to understand the mechanics of the various weather securities), but it is not a prerequisite. The book will take the reader to the level where he is expected to be able to apply the proposed methodologies in modeling and pricing weather derivatives in any desired location on different weather variables.

Through extensive examples and case studies, this book provides a step-by-step guide for modeling and pricing various weather derivatives written on different weather variables. The content is written in an easy to understand way, and the methodologies are separated in various stages for a better understanding, constituting the book a guidebook for both investors and students and helping them to apply the methodologies in order to achieve a successful weather risk management strategy and accurate weather derivative pricing.

This book is aimed to be used (*a*) by weather-sensitive companies in sectors like energy, electricity, agriculture, transportation, retail, construction, and entertainment, whose revenues are exposed to weather risk and are interested in weather risk management, and (*b*) by students in advanced postgraduate programs in finance, MBA, and mathematical modeling courses as well as in agriculture, energy sector, mathematical, meteorological, and engineering sciences that are seeking employment in the mathematical modeling and financial services industry. In addition, the book is aimed to be used (*c*) by researchers in incomplete financial markets, in alternative investments, electricity and CO_2 markets, and in relevant Ph.D. programs and finally, (*d*) by investment professionals in investment institutions such as banks, insurance companies, security houses, fund managers, institutional investors, companies with intensive international activities, and financial consultancy firms.

During the writing stages of this book, the help of Christina Ioannidou was significant, and we would like to thank her.

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List of Abbreviations

AccHDD	Cumulative heating degree day
AccCDD	Cumulative cooling degree day
ACF	Autocorrelation function
ADF	Augmented Dickey–Fuller
AIC	Akaike's information criterion
AR	Autoregressive
ARCH	Autoregressive conditional heteroskedasticity
ARFIMA	Autoregressive fractional integrated moving average
ARIMA	Autoregressive integrated moving average
ARMA	Autoregressive moving average
AROMA	Autoregressive on moving average
BP	Back-propagation
BE	Backward elimination
BIC	Bayesian information criterion
BM	Brownian motion
BS	Bootstrap
CAR	Continuous autoregressive
CAT	Cumulative average temperature
CAWS	Cumulative average wind speed
CET	Central European time
CDD	Cooling degree day
CDF	Cumulative density function
CME	Chicago mercantile exchange
CR	Cumulative rainfall
CV	Cross-validation
DAT	Daily average temperature
DAWS	Daily average wind speed
ECAD	European climate assessment & dataset
ECMWF	European centre for medium-range weather forecasts

EEX	European energy exchange
ENSO	El Niño–Southern oscillation
FBM	Fractional brownian motion
FPE	Akaike's final prediction error
FT	Fourier transform
GARCH	Generalized autoregressive conditional heteroskedastic
GCV	Generalized cross-validation
HBA	Historical burn analysis
HDD	Heating degree day
HU	Hidden unit
IPOCID	Independent prediction of change in direction
JB	Jarque–Bera
KPSS	Kwiatkowski–Phillips–Schmidt–Shin
LLF	Log likelihood function
MAE	Mean absolute error
MAPE	Mean absolute percentage error
Max AE	Maximum absolute error
MC	Monte Carlo
MLE	Maximum likelihood estimation
MPR	Minimum prediction risk
MRBM	Mean reverting Brownian motion
MSE	Mean square error
NCDC	National climatic data center
NCEF	National center of environmental forecasts
NESDIS	National environmental satellite, data and information service
NIG	Normal inverse Gaussian
NMSE	Normalized mean square error
NN	Neural network
NOAA	National oceanic and atmospheric administration
NYMEX	New York mercantile exchange
OPEC	Organization of petroleum exporting countries
ORBS	Orthogonalized residual based selection
OTC	Over-the-counter
OU	Ornstein–Uhlenbeck
PAC	Pacific rim
PACF	Partial autocorrelation function
PCA	Principal component analysis
PDF	Probability density function

POCID	Prediction of change in direction
POS	Position of sign
RBFN	Radial basis functions networks
RBS	Residual based selection
RMSE	Root mean square error
SAROMA	Seasonal autoregressive on moving average
SBP	Sensitivity based pruning
SSO	Stepwise selection by orthogonalization
WA	Wavelet analysis
WDC	World data center for meteorology
WN	Wavelet network
WRT	With respect to
WTI	West Texas intermediate

Chapter 1
The Weather Derivatives Market

1.1 Introduction

Weather derivatives are financial instruments that can be used by organizations or individuals as part of a risk management strategy to reduce risk associated with adverse or unexpected weather conditions. Just as traditional contingent claims, whose payoffs depend upon the price of some fundamental, a weather derivative has an underlying measure such as rainfall, temperature, humidity, or snowfall. The difference from other derivatives is that the underlying asset has no value and it cannot be stored or traded while at the same time the weather should be quantified in order to be introduced in the weather derivative. To do so, temperature, rainfall, precipitation, or snowfall indices are introduced as underlying assets.

Today, weather derivatives are being used for hedging purposes by companies and industries, whose profits can be adversely affected by unseasonal weather or, for speculative purposes, by hedge funds and others interested in capitalizing on those volatile markets.

The purpose of this book is to develop a model that explains the dynamics of the various weather variables. A model that describes accurately the evolution of these variables can be later used to derive closed form solutions for the pricing of weather derivatives on various indices. This majority of the material in this book is focused on temperature since the majority of the traded weather derivatives are written on temperature indices. Our findings and proposals can be very useful not only to researchers but also to traders, hedging companies, and new investors.

The rest of the chapter is organized as follows. In Sect. 1.2, the basic aspects of the weather market are discussed. More precisely, in Sect. 1.2.1, the purpose of weather derivatives is presented. The history of the weather marker is presented in Sect. 1.2.2, while in Sect. 1.2.3, the investors that are actively involved in the weather market are shown. In Sect. 1.2.4, various weather securities are described. The differences between weather derivatives and insurance are presented in Sect. 1.2.5. The concept of the basis risk is introduced in Sect. 1.2.6. In Sect. 1.3, the related markets to the weather market are described. More precisely in Sect. 1.3.1 the electricity market is

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described while in Sect. 1.3.2 the oil and gas markets are described. In Sect. 1.4, the main problems of the weather market are presented. The purpose and the usefulness of this book are analytically described in Sect. 1.5. Finally, in Sect. 1.6, an outline of the book and an overview of each chapter are presented.

1.2 The Weather Market

In this section, the basic aspects of the weather market are discussed. More precisely, the purpose of weather derivatives, the history of the weather marker, the investors that are actively involved in the weather market, the weather securities, the differences between weather derivatives and insurance, the basis risk, and finally the common approaches for pricing temperature derivatives are described.

1.2.1 The Purpose of Weather Derivatives

Weather derivatives are financial instruments whose payoffs depend upon the value of some underlying weather index. The underlying weather index can be rainfall, temperature, humidity or snowfall, or any other weather variable. Weather derivatives are used by organizations or individuals as part of a risk management strategy to reduce risk associated with adverse or unexpected weather conditions.

In general, weather derivatives are designed to cover non-catastrophic weather events. Rainy or dry and warm or cold periods which are expected to occur frequently can cause large fluctuation on the revenues of a particular company. A company that uses weather derivatives as a part of its hedging strategy can eliminate the risk related to weather. As a result, the volatility of the year-to-year profits will be significantly reduced. Jewson et al. (2005) present various reasons why this is important. First, low volatility in revenues reduces the risk of great losses and bankruptcy. Second, it decreases the volatility in the share price of the company while it increases the share price. Finally, the interest rate that the company can borrow money is reduced.

Government organizations can also use weather derivatives, in local or national level, in order to avoid unexpected raise in their running costs.

In Jewson et al. (2005) and Cao and Wei (2003), various examples of weather hedging are presented. Weather can affect the revenues of a company directly by affecting the volume of sales. An amusement park that wants to hedge against rainy days in which fewer visitors will be attracted can enter a weather contract written on rainfall. Similarly, an electricity company that wants to avoid a reduced demand in electricity due to a warm winter can use a temperature derivative. A ski resort could use weather derivatives to hedge against a reduced snowfall which will attract fewer visitors. On the other hand, government organization can use weather derivatives in

Table 1.1 Industries with weather exposure and the type of risk they face

Hedger	Weather type	Risk
Agricultural industry	Temperature/precipitation	Significant crop losses due to extreme temperatures or rainfall
Air companies	Wind	Cancellation of flights during windy days
Airports	Frost days	Higher operational costs
Amusement parks	Temperature/precipitation	Fewer visitors during cold or rainy days
Beverage producers	Temperature	Lower sales during cool summers
Building material companies	Temperature/snowfall	Lower sales during severe winters (construction sites shut down)
Construction companies	Temperature/snowfall/rainfall	Delays in meeting schedules during periods of poor weather
Energy consumers	Temperature	Higher heating/cooling costs during cold winters and hot summers
Energy industry	Temperature	Lower sales during warm winters or cool summers
Hotels	Temperature/precipitation	Fewer visitors during rainy or cold periods
Hydroelectric power generation	Precipitation	Lower revenue during periods of drought
Municipal governments	Snowfall	Higher snow removal costs during winters with above-average snowfall
Road salt companies	Snowfall	Lower revenues during low snowfall winters
Ski resorts	Snowfall	Lower revenue during winters with below-average snowfall
Transportation	Wind/snowfall	Cancellation of ship services due to wind or buses due to blocked roads

order to avoid an increase in the costs of cleaning roads in case of snowfall or icy days.

Weather can also affect the revenues or induce costs to the company indirectly, for example, a construction company that experiences delays when constructors cannot work due to weather. Similarly, cancellation of flights due to weather conditions can cause large costs to airlines. In Table 1.1, various industries that are exposed to weather risk and the particular risk that they face are presented.

Trading strategies vary from company to company, and weather derivatives can be used to create profitable investment portfolios in a number of ways (Jewson 2004). High possible returns while keeping the risk very low can be obtained by a portfolio that contains weather derivatives and commodity trades because of the correlation between the weather and commodity prices. Alternatively, adding weather derivatives on a stock portfolio will reduce its risk because of the lack of correlation between the weather derivatives and the wider financial markets. Finally, a diversified portfolio of weather derivatives can give good return for very low risk because of the many different and uncorrelated weather indices on which weather derivatives are based, (Jewson 2004).

1.2.2 The Weather Market History

The necessity of weather products resulted to the creation of a weather market which developed very quickly. Since their inception in 1996, weather derivatives have known a substantial growth. The first parties to arrange for, and issue weather derivatives in 1996, were energy companies, which after the deregulation of energy markets were exposed to weather risk.

Energy and utility companies already had tools for hedging the price of the energy unit. However, as the competition was increasing, the demand in energy was uncertain. Weather affects both short-term demand and long-term supply of energy. A particular pattern of weather conditions, like a warming trend, can affect the long-term supply (Cao and Wei 2003). In addition, weather anomalies could result to severe changes in the price of energy and gas. Therefore, weather derivatives were developed as an effective tool for hedging the volumetric risk, rather than the price risk (Muller and Grandi 2000).

The effects of unpredictable seasonal weather patterns had previously been absorbed and managed within a regulated, monopoly environment. The deregulated environment together with the close association between the short-term demand for energy and the weather conditions created a fertile environment for weather derivatives and the development of the weather market (Cao and Wei 2003).

The first transaction in the weather derivatives market took place between 1996 and 1997. The weather transaction was executed by Aquila Energy as a weather option embedded in a power contract (Considine 2000). The first public weather derivative transaction was between Koch Energy and Enron in 1997 in order to transfer the risks of adverse weather. The deal was concerning a temperature index for Milwaukee for the winter of 1997–1998. Since then, the weather market has quickly expanded. In the following years, transaction in Europe, Asia, and Australia took place.

In September 1999, the Chicago Mercantile Exchange (CME) launched the first exchange-traded weather derivatives. In Fig. 1.1, a categorization of the financial derivatives traded in the CME is presented. CME's contracts represent the first exchange-traded, temperature-based weather derivatives (Cao and Wei 2003). The CME offered new weather derivatives in various cities in the USA, attracting more participants. Initially, weather derivatives were offered in 10 cities which were chosen based on population, the variability in their seasonal temperatures, and the activities seen in over-the-counter (OTC) markets. The regulatory system offered by the CME helped the market to evolve. The CME eliminated the default risk. Moreover, the transparency on the transactions was increased since the prices of the contracts were public. Consequently, the weather market attracted new participants.

In 2004, the national value of CME weather derivatives was $2.2 billion and grew tenfold to $22 billion through September 2005, with open interest exceeding 300,000 and volume surpassing 630,000 contracts traded. However, the OTC market was still more active than the exchange, so the bid-ask spreads were quite large.

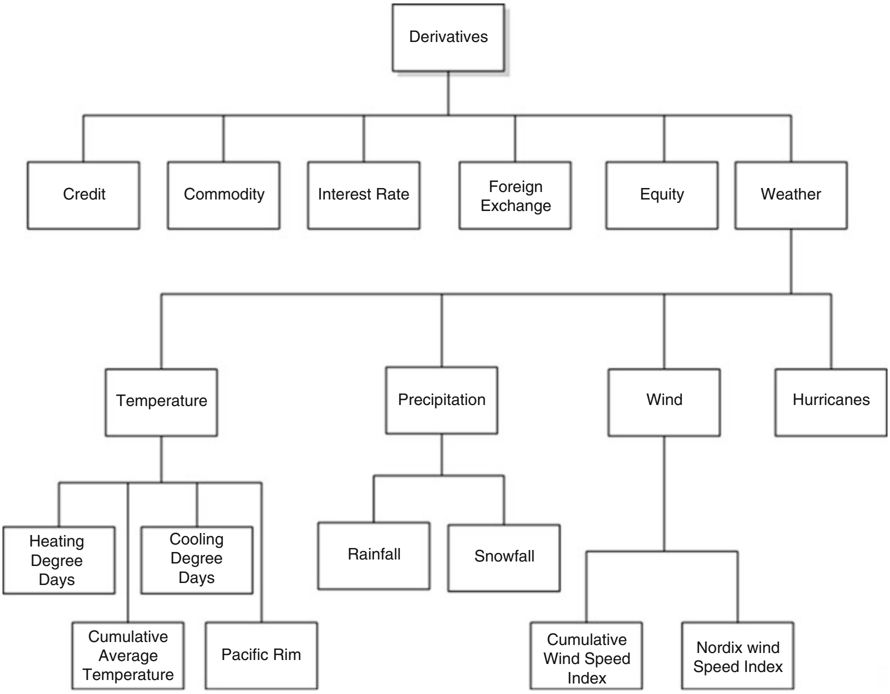

Fig. 1.1 Categorization of financial derivatives

According to the annual survey by the Weather Risk Management Association (WRMA 2009), the estimated national value of weather derivatives – OTC and exchange-traded – traded in 2008/2009 was $15 billion, compared to $32 billion the previous year and $45 billion in 2005–2006. However, there was a significant growth compared to 2005 and 2004 (Ceniceros 2006). According to CME, the recent decline reflected a shift from seasonal to monthly contracts.

Although the overall number of contracts decreased, following the general decline in financial markets, the weather market continues to develop, broadening its scope in terms of geography, client base, and interrelationship with other financial and insurance markets. In Asia, the number of contracts in 2009 rose to 250% compared to the period of 2007–2008. In Europe, there were 34,068 contracts traded in 2008–2009 compared to the previous year's 25,290 (WRMA 2010).

The weather derivatives market is organized as any other financial market. Hedgers and speculators are involved on transactions. Transaction between hedgers and speculators takes place in the primary market. In the secondary market, speculators trade between themselves.

The group of hedgers consists of companies who buy weather derivatives to hedge the weather risk in their businesses, while the group of speculators consists of banks, insurance companies, reinsurance companies, and hedge funds. Speculators are involved in trading weather derivatives in order to make a profit rather than to hedge their risks.

Today, weather derivatives can be structured in order to cover almost any weather variable for various periods ranging from a week to several years.

1.2.3 Market Participants

According to Challis (1999) and Hanley (1999), nearly $1 trillion of the US economy is directly exposed to weather risk. It is estimated that nearly 30% of the US economy and 70% of the US companies are affected by weather (CME 2005). The electricity sector is especially sensitive to the temperature. According to Li and Sailor (1995) and Sailor and Munoz (1997), temperature is the most significant weather factor explaining electricity and gas demand in the United States. The impact of temperature in both electricity demand and price has been considered in many papers, including Henley and Peirson (1998), Peirson and Henley (1994), Gabbi and Zanotti (2005), Zanotti et al. (2003), Pirrong and Jermakyan (2008), and Engle et al. (1992). Hence, it is logical that energy companies are the main investors of the weather market. In 2004, the 69% of the weather market was consisting of energy companies. As more participants were entering the market, the energy companies were corresponding to 46% of the weather market in 2005.

Agricultural companies are greatly affected by weather conditions. However, only recently, companies from the agricultural sector started to participate in the weather market. The willingness to pay for climate derivatives is measured in Edwards and Simmons (2004) and Simmons et al. (2007). Under a general class of mean–variance utility functions with constant absolute risk aversion, they conclude that there is a demand for climatic hedging tools by wheat farmers. In Asseldonk (2003), Dubrovsky et al. (2004), Edwards and Simmons (2004), Harrington and Niehaus (2003), Hess et al. (2002), Lee and Oren (2007), Myers et al. (2005), Simmons et al. (2007), and Turvey (2001), the impact of the weather risk management for agricultural and agri-business is discussed.

Transportation, public utilities, retail sales, amusement and recreation services, and construction sectors are also very sensitive to weather (Dutton 2002). Figure 1.2 presents the participation of various industry sectors in the weather derivatives market. It is clear that until 2005, the weather derivatives markets were dominated by energy companies. However, as weather derivatives gain popularity, new players enter the market especially from agriculture and retail sectors.

The development of the weather market draws new members whose profits do not depend on weather conditions, like insurers and reinsurers, investment banks, and hedge funds.

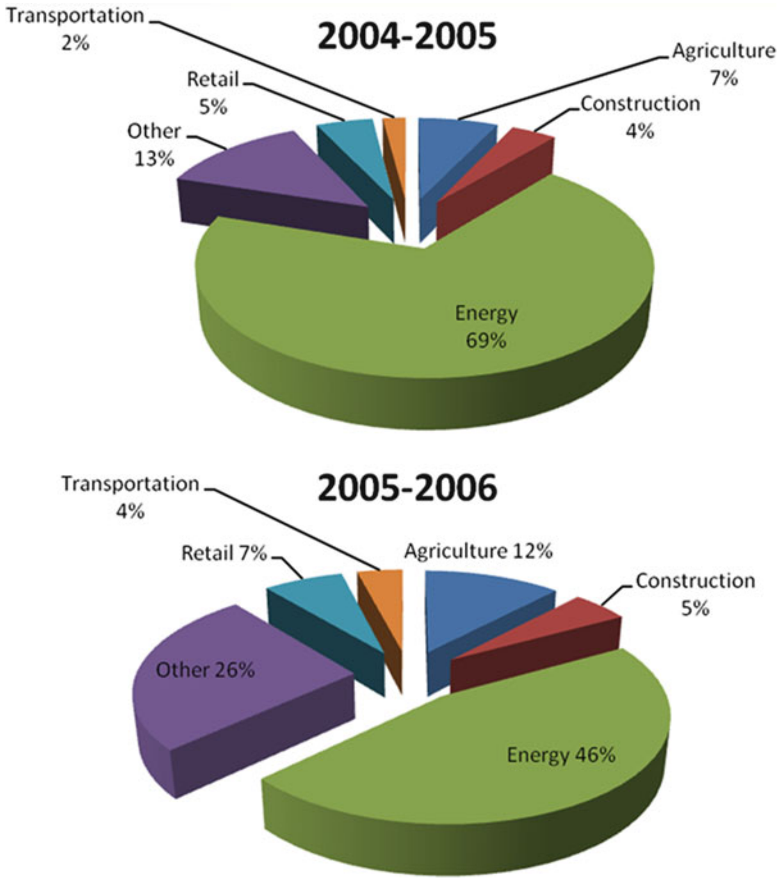

Fig. 1.2 Weather derivative potential by sector in 2004–2005 and 2005–2006 (Data obtained from WRMA. www.wrma.org)

Investment banks understood the potential of weather derivatives as a financial risk management product that they could cross sell along with other financial products for hedging interest rate or currency risks.[1] Finally, some commodity traders and hedge funds saw opportunities to trade weather on a speculative basis, or to take advantage of arbitrage opportunities relative to other energy or agricultural commodities.[2]

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[1] Climetrix, http://www.climetrix.com/WeatherMarket/MarketOverview/default.asp

[2] Climetrix, http://www.climetrix.com/WeatherMarket/MarketOverview/default.asp

1.2.4 Weather Securities

The list of traded contracts on the weather derivatives market is extensive and constantly evolving. The CME offers various weather futures and option contracts. They are index-based products geared to average seasonal and monthly weather in 46 cities[3] around the world – 24 in the USA, 10 in Europe, 6 in Canada, 3 Australian, and 3 in Japan. At the end of 2009, the CME trades weather products written on the following 10 European cities: Amsterdam, Barcelona, Berlin, Essen, London, Madrid, Oslo, Paris, Rome, and Stockholm. In the USA, there are contracts for the following 24 cities: Atlanta, Baltimore, Boston, Chicago, Cincinnati, Colorado Springs, Dallas, Des Moines, Detroit, Houston, Jacksonville, Kansas City, Las Vegas, Little Rock, Los Angeles, Minneapolis–St. Paul, New York, Philadelphia, Portland, Raleigh, Sacramento, Salt Lake City, Tucson, and Washington D.C. Also, there are 6 Canadian cities, Calgary, Edmonton, Montreal, Toronto, Vancouver, and Winnipeg; 3 Australian cities, Brisbane, Melbourne, and Sydney; and finally, there are 3 Japanese cities, Hiroshima, Tokyo, and Osaka.

However, over 95% of the contracts are written on temperature heating degree days (HDD), cooling degree days (CDD), pacific rim, and cumulative average temperature (CAT) indices.

In Europe, CME weather contracts for the summer months are based on an index of CAT. The CAT index is the sum of the daily average temperatures (DATs) over the contract period. The average temperature is measured as the simple average of the minimum and maximum temperature over 1 day.

In the USA, Canada, and Australia, CME weather derivatives are based on the HDD or CDD index. A HDD is the number of degrees by which the daily temperature is below a base temperature, and a CDD is the number of degrees by which the daily temperature is above the base temperature. The base temperature is usually 65 °F in the USA and 18 °C in Europe and Japan. HDDs and CDDs cannot be negative, and usually, they are accumulated over a month or over a season. The CME also trades HDD contracts for the European cities.

For the three Japanese cities, weather derivatives are based on the Pacific Rim Index. The Pacific Rim Index is simply the average of the CAT index over the specific time period.

A weather contract is specified by the following parameters (Alaton et al. 2002):

- The contract type
- The strike or future price
- The tick size
- The maximum payout
- The contract period
- The underlying index (CAT, HDDs, rainfall, snowfall)
- Weather station from which the underlying variable data are obtained
- A premium paid from the buyer to the seller (negotiable)

---

[3] The number of cities that the CME trades weather contracts at the end of 2009

Weather derivatives are based on standard derivative structures such as puts, calls, swaps, collars, straddles, and strangles. As in the classical financial derivatives, the payout of these contracts depends on the strike price (the value at which the underlying index may be bought or sold) and the tick size (the smallest increment of the index that leads to a payout amount). Usually, the payout of the contract is capped. A cap in the payout is added in order to protect the two parties against extreme adverse weather conditions. In option derivatives, a premium must be given from the buyer to the seller. The premium is the price of the option.

All contracts have a defined start date and end date that constrains the period over which the underlying index is calculated. The period of the contract can range from 1 week to several years. In CME monthly and seasonal contracts are traded. Some contracts have more specific periods such as the measurements of the underlying index are considered only in working days and not at weekends.

In the contract, the underlying index must be specified. The underlying index is based on a weather variable and defines the payoff of the contract. Usually, contracts are written on CDDs, HDDs, or CAT over a specified period. Some derivatives are based on event indexes which count the number of times that temperature exceeds or falls below a defined threshold over the contract period. Similar indexes are also used for other variables, for example, cumulative rainfall or the number of days on which snowfall exceeds a defined level.

All weather contracts are based on the actual observations of weather at one specific weather station. A backup station is used in the case the main station fails. Most transactions are based on a single station, although some contracts are based on a weighted combination of readings from multiple stations and others on the difference in observations at two stations.

1.2.5 Weather Derivatives and Insurance

In the past, insurance contracts and catastrophe bonds were widely used by companies in weather-sensitive industry sectors. Like insurance contracts, the purpose of weather derivatives is to protect the buyer of the contract against adverse weather conditions. In other words, weather derivatives also provide insurance against fluctuations of the weather conditions. However, a closer inspection of these two products reveals many differences.

The first difference is the weather events that each tool covers. Insurance contracts are written on rare weather events such as extreme cold or heat and hurricanes or floods. These events are highly liked to create great catastrophes with huge impact on the revenues of the company. In contrast, weather derivatives can protect a company from recurrent weather conditions with large probability of occurrence. Unlike insurance and catastrophe-linked instruments, which cover high-risk and low-probability events, weather derivatives usually shield revenues against low-risk and high-probability events (e.g., mild or cold winters).

Claiming compensation from an insurance company usually is time consuming and expensive. The insured party must first prove that the weather had catastrophic effects on his company while the outcome depends on the subjective opinion of each regulator. On the other hand, in the case of weather derivatives, the company receives the profit of the contract immediately. In addition, there is no need for a catastrophe to occur on the company in order to receive the compensation. Weather derivatives are based on objective criteria like the index of the temperature, the rainfall, or any other underlying index which is accurately measured on a predefined weather station.

Another advantage of weather derivatives is the additional freedom that they offer to the buyer in contrast to the insurance contracts. Hedging the impact of the weather on the competitive companies using weather derivatives is possible. For example, an agricultural company on area A can hedge against weather effects in a different area B where a competitive company is established. Favorable weather conditions in area B will result to the increase of the quantity and quality of a particular agricultural product in area B. Consequently, the demand and price for this particular product from the company in area A will decrease.

Finally, since weather derivatives are financial instruments, a weather derivative can be later sold in a third party, for speculative reasons, before the expiration day of the contract.

Companies, especially, on the agriculture and energy sector can significantly benefit from the advantages that weather derivatives offer as a weather risk management tool, (Hess et al. 2002; Pirrong and Jermakyan 2008; Simmons et al. 2007; Turvey 2001).

1.2.6 Basis Risk

Weather risk is unique in that it is highly localized, and despite great advances in meteorological science, it still cannot be predicted precisely and consistently. Risk managers often face unique basis risks arising from both the choice of weather station where a derivatives contract is written as well as the relationship between the hedged volume and the underlying weather index (Manfredo and Richards 2009). We will refer to the first as spatial or geographical basis risk, while to the second as basis risk.

The exchange-traded weather derivatives eliminated the default risk while at the same time the liquidity and the transparency increased. On the other hand, investors who wish to trade weather derivatives outside the list of the traded cities in CME face a spatial risk.

Geographical basis risk results from the distance between the hedging company and the site at which the weather measurement takes place. Geographical basis risk can reach critical levels in some cases (Rohrer 2004). As the distance between a hedging company and the measurement weather station of the weather derivative increases, the demand for weather derivative decreases (East 2005; Edwards and Simmons 2004).

It is expected that spatial risk will always be positive. However, Woodard and Garcia (2008) show that weather derivatives from a variety of stations around the hedging company can improve the hedging effectiveness. Using nonlocal derivatives for a weather variable that is highly spatially correlated, the hedging strategy obtained may be as good as the one obtained using locally derived contracts (Woodard and Garcia 2008).

In many studies, energy and weather are considered highly correlated. Hence, companies from the energy sector are extensively using weather derivatives to hedge both the price and volumetric risk of energy demand (Gabbi and Zanotti 2005; Henley and Peirson 1998; Pirrong and Jermakyan 2008). Moreover, weather derivatives are used for the valuation of gas and CO_2 emissions contracts (Bataller et al. 2006; Zanotti et al. 2003; Geman 1999).

However, these two variables, energy and temperature (or any other weather variable), are not perfectly correlated. The payoff of the weather derivative depends on the weather index, and it is unlikely that the payoff will compensate exactly for the money lost due to weather (Jewson et al. 2005). As a result, a risk is induced on the hedging strategy, called basis risk. As the correlation between the weather index and the financial loss increases, it is expected of the basis risk to decrease.

The study and understanding of spatial and basis risk will draw new participants to the weather market.

1.3 Weather Derivatives and Related Markets

In this section, we will examine the markets that are closely related to the weather market. The energy market, for example, electricity, oil, and gas, has similar characteristics to the weather market. Many power companies trade also weather derivatives due to the high correlation of the underlying variables between the two markets. Energy companies are among the most active and sophisticated users of derivatives (Hull 2003). Many energy products trade in both the OTC and on exchanges.

1.3.1 The Electricity Market

As it was mentioned earlier, the weather market emerged by contracts developed by energy companies. At the same time, the majority of the participants in the weather market consist of companies from the energy sector. On the other hand, temperature and electricity consumption and prices are highly correlated.

After the deregulation of the energy market in the early 1990s, the energy companies developed financial derivatives on electricity price in order to hedge themselves against excess production and limited consumption of electricity. Electricity is the same as any weather variable in the sense that it cannot be stored.

Table 1.2 Wholesale electricity markets

Location	Power exchange	Website
Scandinavia	Nord Pool Spot	http://www.nordpoolspot.com/
France	Powernext	http://www.powernext.fr/
Germany	EEX	http://www.eex.com/
Great Britain	Elexon	http://www.elexon.co.uk/
India	PXIL	http://www.powerexindia.com/
USA	PJM	http://www.pjm.com/
USA	NYMEX	http://www.cmegroup.com/company/nymex.html
USA	New York market	http://www.nyiso.com/

Furthermore, it has to be consumed exactly at the same time as it is produced. As a result, the electricity market cannot be considered complete, and the arbitrage-free pricing approach cannot be applied. Hence, there is a need in energy market for real time balancing between supply and demand. The excess power is sold to another control area through a transmission line. Although supply and demand are the two key factors determining the price, transmission capacity and costs also play a role.

Each area has to secure its supply of electricity and the stability of its network. This is the role of a transmission system operator. The system operator in a deregulated market has to be a noncommercial organization and independent with regard to the market participants. The operator should not own any generating assets that could benefit from its decisions. In addition, the independent system operator has the superior, physical ruling and control of the energy system in his area.

In Table 1.2, the electricity exchanges in the world are presented. The larger are the Nord Pool that covers the area of the Scandinavia, the European Energy Exchange (EEX) located in Germany, and the NYMEX and PJM in the USA which is world’s largest wholesale electricity market. Each power exchange has its own pricing mechanism, products, and settlement principals.

The contracts traded in the weather market are divided in two categories. In the first category, physical delivery of electricity is needed, while in the second one, there is cash settlement of the contracts.

The day-ahead market is the main market where contracts between buyer and seller have physical delivery of energy the next 24 h. Usually, a utility company has the role of the buyer. Each day, the buyer bids for price and the amount of electricity that he needs for the following day, hour by hour. Similarly, the seller, usually an electricity production unit, announces the price and the amount of electricity he can deliver the next day, hour by hour. At the Nord Pool, at 12:00 CET is the time of gate closure for bids. The offer orders are aggregated to form the supply curve, while bid orders are aggregated to form the demand curve. The price is set where the curves for sell and buy intersect for each hour and the price is announced to the market at 13:00 CET, and after that, the contracts are settled. From 00:00 CET the next day, the settled contracts are delivered physically hour by hour.

Each market is divided in different control areas. Hence, in case of congestion of power flow, area prices are calculated as mechanism to relieve the power grid. More specifically, the price in area with the excess electricity is lowered in order to lead to an increase in purchase and a decrease in sale. On the other hand, the price is increasing in the area with lower-electricity production, so the participants in this area will sell more and purchase less.

There is also the so-called intraday market. In Nord Pool, this market is called Elbas and helps to secure the necessary balance between supply and demand in the power market for northern Europe. Balancing between supply and demand is also secured in the day-ahead market. However, there is a possibility that some incident between the closing time and the delivery at the next day may break this balance. In the intraday market, participants can trade electricity close to real time prices in order to bring the market back to balance.

Elbas is a continuous market, and participants can trade 24 h a day until 1 h before delivery. Prices are set based on the best prices. The prices are ranked where highest-buy price and lowest-sell price are the best prices.

The participants in the electricity market are energy producers and retailers, traders, brokers, financial analysts, and clearing companies. Also, large end users trade at the exchange and in order to obtain electricity directly from the market instead of doing it through a supplier.

On the other hand, contracts with financial cash settlement are used for price hedging and risk management. Usually, these contracts have duration from a day to up to year and have a time horizon up to 6 years (at Nord Pool). In these contracts, there is no physical delivery of electricity. The contracts are settled with cash, while cash settlements take place daily.

1.3.2 The Oil and Gas Market

Crude oil is considered one of the most important commodities since it constitutes a decisive factor in the configuration of prices of all the other commodities while its price fluctuation is an indication and also a cause of important changes in global economies. The rise, the stability, or the decline of crude oil prices have a direct impact in the economies of various states but also in the more general international economy. Both oil and natural gas are widely used for heating and electricity production. As any commodity, the prices of oil and gas are determined by supply and demand.

The oil and gas market is sharing a lot of characteristics with the electricity market. However, unlike energy and weather, both oil and gas can be stored and traded. The market is split between the financial market and the physical market, the price paid for actual deliveries of natural gas and individual delivery points around the United States. In general, market mechanisms, although they vary between the USA and Europe, are similar.

Both oil and gas can be traded through New York Mercantile Exchange (NYMEX). Henry Hub and Pine Prairie Energy Center is the pricing point for natural gas future contracts traded on the NYMEX. On the other hand, oil is traded in various West Texas Intermediate (WTI), Brent, and Russian Export Blend Crude Oil indices.

Similar to the electricity market, both oil and gas demands are highly correlated to temperature. As a result, both their prices and volume are fluctuating, depending on the temperature. For example, a mild winter will result to a significant lower demand for gas and oil for heating. As a result, the consumption of oil and gas will decrease which will lead to a decrease in prices.

However, many other factors affect the final price of oil and gas. For example, global demand for petroleum products is highly seasonal, and it is higher during the winter months, when countries increase their use of distillate heating oil and residual fuels. Supply of crude oil, including both production and net imports, also shows a similar seasonal variation. Finally, OPEC's (Organization of Petroleum Exporting Countries) decisions have had considerable influence on international oil prices, for example, in the 1973 oil embargo which resulted to a great increase in prices and an economic recession throughout the world. OPEC is an intergovernmental organization of 12 oil-producing countries.[4] OPEC's objective is to coordinate and unify petroleum policies among member countries in order to secure fair and stable prices for petroleum producers; an efficient, economic, and regular supply of petroleum to consuming nations; and a fair return on capital to those investing in the industry (OPEC 2012).

1.4 Weather Derivatives Pricing and Other Issues

It is clear that the weather market is developing rapidly as more investors and participants are actively involved. Nevertheless, there are still some issues that are hampering the further development of the market. A generally accepted pricing model, like the Black–Scholes model, does not exist. Also, many companies have to deal with spatial and basis risk. Finally, the market is still relatively illiquid while practitioners and risk management companies keep weather market data private and do not publish their models.

Solving the first two problems would attract new participants in the market, and the liquidity would increase. By extending the existing list of weather indices, companies would be able to match the weather effects to their loss of revenues, and by expanding the list of cities that the CME trades, weather derivatives would reduce the spatial risk.

As we have already mentioned, in this book we focus on temperature, wind, and precipitation derivatives. A generally accepted framework for pricing temperature (or in general weather) derivatives does not exist. Most investors use the historical burn analysis (HBA) pricing methodology, (Dorfleitner and Wimmer 2010),

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[4] Algeria, Angola, Ecuador, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the United Arab Emirates, and Venezuela