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ABSTRACT

In this paper we describe the major issues in the weather risk management. We focus on the management of financial risks connected with weather. We first provide a general discussion of the impact of weather on the economy. Then we follow with the overview of the development of the weather risk management. The core of the paper in then devoted to the role of weather derivatives as financial tools for weather risk management.

Key words: Financial risk, Weather risk, Derivatives, Energy.

JEL classification: C10, C20, G12, G13.

Introduction

In this paper we focus on the applicability of temperature-based derivatives as tools of managing weather risk. Nowadays, as the discussion on global climate change is gaining intensity, interest in the relationship between weather, or more generally said environment, and economy is spreading with enormous speed all around the world. There are dozens of authors that are trying to express in numbers the dependency of economy on weather and consequently evaluate the risks affiliated to weather. Since results are usually very miscellaneous, it is obvious that evaluation of these risks in not an easy task. Impacts of weather vary with economic sectors as well as with geographic regions and compared with other forces that bring some cost to economy, they have quite specific position.

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We have to realize that weather is completely beyond human control. No one can influence, modify or manipulate it (regarding climate changes, it would be for a long discussion, of course). Moreover, no one can even forecast weather beyond the horizon of few days with enough accuracy. These aspects heavily contribute to the uniqueness of so called “weather risk”.

Wide flexibility in design of specific weather indices facilitates the development of innovative hedging structures that are used to manage a large scale of weather-related risks. Weather indices on temperature, precipitation, snowfall, wind or other weather features can be used for different locations as well as different time periods including days, weeks and months.

Ruck (2001) refers to several basic questions that should be answered before making a decision on hedging weather risks in order to help with the development of a successful strategy:

- How much weather risk can be tolerated?
- What is the minimum acceptable revenue, net income or unit sales level?
- How do the Board of Directors and senior management view hedging?
- Are premium payments acceptable, or must the hedge be cost less?
- Is there any accounting or tax implication associated with hedging weather risk?
- Are there any regulatory issues to consider?

With regard to other factors, such as the financial rating of counter-party or provided customer services, a company that is considering pros and cons of a potential hedge may get a notion that could greatly help to decide. Nevertheless, the decision is in the end usually based on a cost-benefit analysis that examines possible financial impact of a hedge.

A business with weather exposure may choose to buy or sell a futures contract, where one party is paid if degree days exceed a pre-determined level while another gets a payment in the opposite case. However, the majority of traded weather derivatives are put or call options, occasionally also combinations of both types.

In the remainder of this paper we first provide a general discussion of the impact of weather on the economy. Then we follow with the overview of the development of the weather risk management. The core of the paper in then devoted to the role of weather derivatives as financial tools for weather risk management.

1. Impact of weather on the economy

In this paper we focus mainly on weather related topics. However, due to the concern over global climate change around the globe today, also dozens of studies dealing with climate risks have been commissioned. Therefore, it is necessary to make a distinction between both terms - weather and climate. Even though the difference between them is quite obvious at the first sight, let us now define both terms to avoid possible misunderstandings. General definition[1] of weather says that it is *"... current, rather than average, atmospheric conditions; the object of study of synoptic meteorology. Weather variables include humidity, temperature, sunshine hours, cloud cover, visibility, and precipitation (fog, rain, snow, sleet, and frost)."* The same source defines climate as follows: *"A summary of mean weather conditions over a time period; usually based on thirty years of records. Climates are largely determined by location with respect to land – and sea-masses, to large-scale patterns in the general circulation of the atmosphere, latitude, altitude, and to local geographical features."*

In other words, if you look out of your window, it will be weather you see anytime. But if you are repeating this for a month, quarter of a year or even years, you will be able to determine the climate outside. All definitions of these terms correspond to the general feeling that climate is much a long-run event.

1. 1. Weather sensitivity

Precise assessing of weather sensitivity of various economic sectors is not an easy assignment. There have been published many papers, mainly in the United States (U.S.), dealing with the topic of weather sensitivity of economy. According to Larsen (2006) there do not exist any economic definitions of being economically sensitive to weather. However, one may find applicable definitions of sensitivity in the literature about climate. The United Nations Environment Programme (2001) defines sensitivity as: *"... the degree to which a system will respond to a change in climatic conditions."* Despite the fact that there are greatly diverse time horizons when talking about weather and climate, the definition of sensitivity is in general plausible for both cases. Therefore, if there is an adverse (or potentially beneficial) impact of weather on economic sectors, either direct or indirect, they are considered to be economically weather sensitive. Nevertheless it is important to define this sensitivity objectively as there usually exists the tendency to do it in a subjective way.

Larsen (2006) further claims that: "*A super-sector could be deemed objectively sensitive to weather (relative to another super-sector) if repeatedly drawing from a distribution of observed weather variables (e.g. temperature, precipitation) in a geographic region produces measurable changes in the variance of the dependent variable (e.g. sales of cars, agricultural yields, or some measure of sector output) estimated from a robustly fit regression equation."* He emphasizes the existence of a meteorologists' fraction which speculates that practically all sectors of the economy of the U.S. are

[1] According e.g. to: http://www.answers.com/topic/weather.

weather sensitive. The U. S. is estimated to have total weather sensitivity of $2.5 trillion dollars, about 23 percent of the whole national economy.[2]

Dutton (2002b) supposes that about $3.9 trillion of the $9.9 trillion U.S. Gross Domestic Product (GDP) in 2000 was sensitive to weather. Expressed in percentages, 39.1% of the national GDP was affected by weather with the following components listed as weather sensitive:

- agriculture, forestry and fishing
- mining
- constructing
- transportation and public utilities
- retail trade
- finance, insurance and real estate
- services

"The conclusion is that some one-third of the private industry activities, representing annual revenues of some $3 trillion, have some degree of weather and climate risk. This represents a large market for atmospheric information, and it should represent a powerful force for advancing the cause of atmospheric observation and prediction," Dutton says.

Despite the fact that results of particular studies vary, it is obvious that a large portion of the U.S. economy is highly, directly or indirectly, affected by weather. Although this topic has been widely discussed in recent years, it is still very difficult to quantify the results objectively since authors tend to be in their analyses always subjective. Some level of subjectivity has to be generally used both in definition of:

- the manner of empirical testing at the national level
- the meaning of being sensitive

1. 2. Characterization of weather

Dutton (2002b) defines weather and climate risk in a more comprehensive way as the possibility of injury, damage to property or financial loss due to severe or extreme weather events, unusual seasonal variations such as heat waves or droughts or long term changes in climate or climate variability.

Although we devote this paper to weather and associated risks, also the discussion on climate and its change of course greatly helped to popularize the term "weather risk". We are interested in the topic of temporary weather changes that may mean even the period of a couple of months, even though continual changes of climate are not a topic of lower importance compared with short term weather variations. In the short term it is more obvious what the costs of a possible change are. It is the aim of

[2] Weatherbill Inc. (2008): *Global Weather Sensitivity: A Comparative Study.*

all companies to quantify all possible weather threats and hedge against them in the best way that they are able to do.

Figure 1: Links between weather and financial risks

risk holder	weather type	risk
energy industry	temperature	lower sales during warm winters or cold summers
energy consumers	temperature	higher heating/cooling costs during cold winters and hot summers
beverage producers	temperature	lower sales during cold summers
building material companies	temperature/snowfall	lower sales during severe winters (construction sites shut down)
construction companies	temperature/snowfall	delays in meeting schedules during periods of poor weather
ski resort	temperature	lower revenue during winters with below-average snowfall
agricultural industry	temperature/snowfall	significant crop losses due to extreme temperatures or rainfall
municipal governments	temperature	higher snow removal costs during winters with above-average snowfall
road salt companies	temperature	lower revenues during low snowfall winters
hydro-electric power generation	precipitation	lower revenues during periods of drought

Source: Mitu, N. M. (2008)

As companies commonly use some normal weather patterns to build their business plans, contingent anomalies may cause an unwelcome surprise. All possible changes of weather affect consumed volumes of commodities. Thus, weather risk is commonly titled also as volumetric risk. Some of real-life weather impacts on volumes are listed in Figure 1. Even though volumes of consumed commodity are influenced at first, the price bears the heaviest impact in the end. With both prices and volumes being destabilized by weather, companies have to fight against those threats and manage their risk exposure.

Considering weather risk management, one may immediately imagine some kind of insurance against abnormal weather events. Even though it is a reasonable consideration as these types of coverage are quite popular, they represent just a small portion of weather risk management today, which has greatly developed and showed its enormous potential over the last ten years.

Weather-related insurance products have long been available. However, sharp increase of interest in weather risk came with the beginning of energy markets' deregulation that attracted also capital markets. Therefore new capital market products, called weather derivatives, appeared as an outgrowth of the liberalization of the energy industry.

- ***Weather Risk on energy markets***

In energy markets weather influences chiefly the demand side. Nevertheless, when there are highly unfavourable weather conditions like a huge storm or even a hurricane, also the supply side of the power network may be harmed as a commodity can not be delivered to customers. Severe weather conditions may for example lead to shut-downs of natural gas wells production, damages on gas pipelines or electricity network, which may be ideal candidates for event-studies. However, in this paper we concentrate primarily on the impact of temperature on natural gas demand.

To have a basic notion how heavy the impact of weather on financial performance may be, let us now go through some experiences of particular companies suffering from changes on the demand side, which were listed in the presentation of RenRe Investment (2008).

- ***Enbridge Gas***:[3] *"Earnings for the year ended December 31, 2006 were $61.8 million compared with $111.9 million for the year ended December 31, 2005. Warmer than normal weather in 2006 reduced earnings by $36.9 million compared with relatively normal weather in 2005 which did not significantly impact earnings."*
- ***Fortis***:[4] *"Electricity sales were 32 GWh, or 2.7%, lower than last year, primarily due to the impact of moderate weather conditions and the loss of an industrial customer in December 2005."*
- ***Gazprom***:[5] *"Fiscal third-quarter net profit for Russian gas firm OAO Gazprom dropped 6.4% to $4.59 bil, due in part to increasing operating costs and unseasonably warmer weather."*

Ameko (2004) provides information on the decrease of revenues of Atmos by $0.20/share and the fall in the share price of Sears Canada by $0.06/share, both due to the non-employing of hedging strategies against adverse weather conditions.

Even though there were always acting also other factors, these cases unambiguously underline the danger linked to the threat of unstable weather. Whenever variations in weather reach extraordinary high levels, it is usually reflected in companies´ financial performances. Especially in the period of growing prices in the energy sector, factors influencing effort of these companies have more important sense than ever.

1. 3. Managers' knowledge

Myers (2008) states that the most senior finance and risk managers in the U.S. realize that their businesses are notably affected by weather since *"… a stunning eight out of ten warn of a new risk:*

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[3] Enbridge Inc. is the leader in energy transportation and distribution in North America.

[4] Fortis Inc. is the largest investor-owned distribution utility in Canada, serving more than 2 million gas and electricity customers.

[5] Gazprom is the world's largest gas company focused on geological exploration, production, transmission, storage, processing and marketing of gas and other hydrocarbons.

that the emergence of global climate change and accompanying volatile weather patterns will require changes to their business models in the decades ahead." But the majority are still just at the beginning of the way to protect themselves from adverse weather effects.

Findings of another survey among 205 senior finance and risk managers at companies in weather-sensitive industries can be found in CME (2008). Based on these results, it is obvious that the U.S. companies, mostly in the energy industry, highly realize the effect of weather on their industries since:

- 59% of managers responded that their companies are highly or very exposed to weather volatility and that they need a protection against this threat
- 43% of surveyed energy and agricultural companies perceives increased volatility of weather in recent years
- 74% of energy companies made a systematic attempt to quantify the impact of weather volatility on their business (while only 29% of retailers did so)
- 51% of all respondents realizes that their companies were not well prepared to cope with weather risk on an everyday basis
- 82% admits possible future changes in the long term business models in order to adjust them to increased weather volatility and climate changes
- from 10% of companies that have already used weather risk management tools (among energy companies it is even higher - 35%), 86 percent say that it was useful

Managers' inadequate knowledge, which has been limiting the growth of the weather risk market for a long time, is in some way understandable. During the period of global financial prosperity, companies did not have to worry so much about potential shortfalls in revenues (e.g. due to adverse weather conditions). Impacts of overlooked weather risks were easily offset by growing corporate profits and easily accessible bank loans.

Apart from the volatile behaviour of weather, there exists also another factor determining the absolute fundamentality of covering potential drop-outs in companies' earnings. As it is inconvenient in the period of financial crisis to compensate assorted financial losses due to lower cash reserves and bank's willingness to provide loans, ignoring weather risk is luxurious!

2. Recent history of weather risk management

2. 1. Deregulation and weather risk management

Deregulation of energy markets in the U.S. was the primary catalyst in shaping the global weather risk market. Prior to deregulation, energy companies commonly used to act in many different roles in the market, e.g. as producers, distributors etc. This has changed with deregulation as companies had to separate their businesses, stopped to be monopolies and started to work in the competitive wholesale market.

The correlation between weather and energy consumption was always well known. However, the impacts of unpredictable seasonal weather patterns were for a long time absorbed and managed within monopoly environment. As soon as monopoly structures were dismantled in the energy industry and utility companies started to be funded by private investors, who were more severe in operating their investments than governments, new investors started to look towards instruments to hedge their weather exposure with the aim of assuring more stable revenue stream.

Many of monopolies were using so called "weather normalization adjustments" to cover additional costs or lower profits caused by illegitimate weather conditions. They were able to pass all these unexpected costs directly to the ratepayer. Since the beginning of deregulation, the situation has dramatically changed as energy companies were no longer able to avoid costs and risks of unpredictable weather behaviour.

There had been methods of transferring weather risk in different industrial or agricultural sectors even before the rise of the weather risk market. Agricultural companies used to sign contracts aimed at preventing possible losses, for example due to drought or hail, and there existed also temperature dependent agreements on power supply. Already in the early 80s Roger Wilcox from National Fuel Gas[6] proposed the concept of Heating Degree Days[7] to manage temperature risk. Some kinds of insuring against weather contingencies were used also by organizers of public events, as sporting events or music concerts are. However, all the contracts signed before 1997 had just a limited scope and none of them actually developed into a real market.

In addition to increasingly popular hedging of price risk applied in ensuring the stability of costs and revenues, energy companies became promptly aware of no possibility to protect against weather risk. As it was not possible to pass increased costs to customers in the case of adverse weather conditions, they had to find a way to hedge against weather variations that drive volumes demanded by customers. That is why several large energy companies in the U.S. started to search for an alternative to offset their risk even in the capital markets, which eventually led to the development of weather derivatives in 1997.

2. 2. Weather risk market's origin

The origin of the weather risk market dates back to the mid 90s, stemming chiefly at the side of energy companies in the U.S. Since energy companies promptly realized that weather conditions were in deregulated markets the main source of uncertainty in revenues, their aim was straightforward – to find instruments stabilizing earnings and thereupon transferring risks of adverse weather. This fact was

[6] National Fuel Gas is one of the earliest gas utility companies in the United States (founded in 1902).
[7] Let us define this term later (Chapter 4).

soon stressed by the El Niňo[8] event, which forced many companies in the U.S. to hedge their seasonal weather risk since they were scared of possible significant declines of earnings due to the extremely warm winter of 1997.

Abnormally high winter temperatures in the U.S. during the El Niňo caused energy companies holding the risk by themselves to regret that they had not fully exploited the possibility of transferring the risk to someone else. Consequently, there were concluded three transactions with weather derivatives in the autumn of 1997. The first pair of transactions, which signified the beginning of the current weather risk market, was signed between Koch Industries, a privately held conglomerate with interests in energy and other commodities, and Enron Corporation. They were based on the temperature index for Milwaukee for the winter 1997/1998 and designed in the way that Koch would pay Enron $10,000 for every degree above normal temperature, while the opposite monetary flow would be invoked by temperatures below normal. Nevertheless, it is important to emphasize that none of these deals would have been signed without the convergence of capital markets and insurance markets proceeding in the 90s.

To sum up, according to the Weather Risk Management Association[9] (WRMA) the new weather risk market combined several features that had been already used before as it:

- provided index based risk transfer per measurable weather variables
- handled temperature, precipitation, snowfall, stream flow, wind speed, daylight hours, humidity or other weather variables
- transferred risk on the basis of aggregate measures (i.e. cumulated over a given period), frequency of appearance of a given weather feature or adverse event per closely related methodologies which integrate the market
- managed risk in ways compatible with both financial and insurance markets
- comprised the primary and secondary market in weather risk

The development of new products for other than energy companies started soon after the emergence of the new market. Since there were requests, e.g. from fertilizer, golf companies or breweries, for other products covering also risks linked to precipitation or wind, additional weather derivatives were created.

[8] El Niňo is a warming of the surface water of the eastern and central Pacific Ocean. It occurs every 4 to 12 years and causes unusual global weather patterns. It mostly affects South America, Australia, and Indonesia, but even the U.S. may be sometimes impacted.

[9] WRMA was founded in 1999 by leading participants in the weather market as the industry association for the weather risk management business. Its purpose is to foster public consciousness of weather risk and its management as well as to promote the growth and general welfare of the weather risk market. [www.wrma.org]

2. 3. Development from the mid 90's

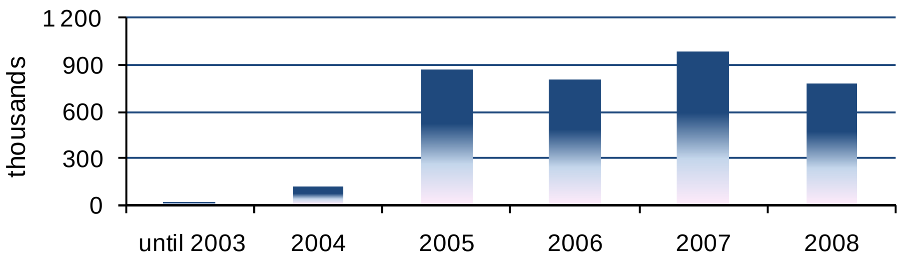
After the first two winters of the El Niňo, energy and utility corporations started to be increasingly active in the weather risk market. Their position as risk holders was subsequently delegated to insurers, banks or hedge funds. Although the trading of weather derivatives began as over-the-counter (OTC), i.e. as concluding privately negotiated agreements directly between two parties, this OTC aspect limited the attractiveness of weather derivatives as an investment vehicle. Therefore Chicago Mercantile Exchange[10] (CME) started to be actively involved in the weather derivatives market in 1999 when it started to list futures and options on temperature indices. From that time, weather derivatives are publicly traded on an open market in the form of standardized contracts.

Traded volumes at CME have experienced a rapid growth in recent years (as shown in Figure 2). Even though there were concluded 4,165 contracts in 2002 and 14,234 one year later, traded volumes reached 776,397 contracts in 2008 and almost incredible 1 million one year earlier. Rapid growth of the weather derivatives market declares also the increased number of cities on whose temperature indices were these instruments written. By the beginning of 2009, CME was already offering weather contracts based on aggregate temperatures in 45 cities[11] while there were only twenty cities used in designing contracts four years earlier.

With regard to the range of offered products, CME has successively enlarged its supply also by listing products used to hedge risks associated with hurricanes, snowfall or frost. With the portion of economy vulnerable to weather, increased number of concluded deals and widened range of products, weather derivatives play today a highly important role in integrated risk management and diversification.

On the other hand, the total number of contracts signed at CME in 2008 reached 3.3 billion. In spite of the fact that weather affects such a high percentage of economy, weather derivatives still create just a fragment of total deals concluded at CME.

Figure 2: Number of weather derivatives contracts at CME



Source: CME Group and Storm Exchange (2008)

[10] Chicago Mercantile Exchange is an American financial and commodity derivative exchange founded in 1898 and based in Chicago. After its merger with the New York Mercantile Exchange in 2008, it creates the world's largest futures exchange.
[11] It included 24 cities throughout the U.S., 10 in Europe, 6 in Canada, 3 in Australia and 2 in Japan.

The weather risk market has moved forward really fast within just a one decade and spread from America also to other continents as it is largely functioning in the North America, Europe or Asia. In addition, it includes a large sphere of actions for e.g. energy industry, agriculture, construction or transportation to entertainment. From the beginning, weather conditions greatly helped to development of the market, with particular trades dominated chiefly by protection against the risk of warm winter. A prominent user of weather derivatives were from the beginning natural gas companies.

A successful hedging of weather risk has become a very important part of a quality risk management in a wide variety of business. Moreover, as weather is today able to change rapidly within few days or even hours, there is still open a large field for the weather risk market to expand. WRMA expects that after its very good start, the market has a presumption to essentially contribute to complex risk management that would affect even more than a third of the global GDP.

3. Weather derivatives

Since various uncertainties have crept into the new competitive natural gas market, either the need for financial derivatives appeared.[12] They primary serve as instruments of transferring price risks to those that are willing and able to bear it.

A financial derivative is widely defined as a financial instrument whose characteristics and value depend on an underlying asset, by which is typically meant a commodity, bond, equity or currency. Even though derivatives' trading techniques might be quite risky and complicated, investors usually purchase or sell derivatives to:

1) manage risk associated with an underlying
2) protect against fluctuations in value
3) profit from periods of decline and financial losses

Apart from the main purpose of derivatives as hedging instruments, certain parties consider derivatives to have also the function of speculative instruments. In both cases, companies have to be very aware that incautious use of derivatives may lead to huge financial losses.

Beside traditional financial derivatives, there exist also their special sorts (with some unique attributes), among which belong also weather derivatives. Geyser (2004) defines weather derivatives as contracts between two parties that stipulate how a payment will be exchanged between parties, depending on certain meteorological conditions during the contract period.

Weather derivatives are today widely available to companies interested in insulating their financial results from variations in weather. With underlying variables as heating degree days, cooling degree days, average temperature, maximum temperature, minimum temperature, humidity, sunshine, or

[12] After the first issue of a natural gas futures contract by NYMEX in 1990, financial derivatives became within few years an important product for all participants in the gas market.

precipitation (both rainfall and snowfall), they are commonly written as weather swaps, futures or options. CME offers several weather derivatives products:

- weather (temperature based) monthly and seasonal futures and options[13]
- frost day monthly and seasonal futures and options
- snowfall seasonal futures and options
- hurricane seasonal and event based futures and options

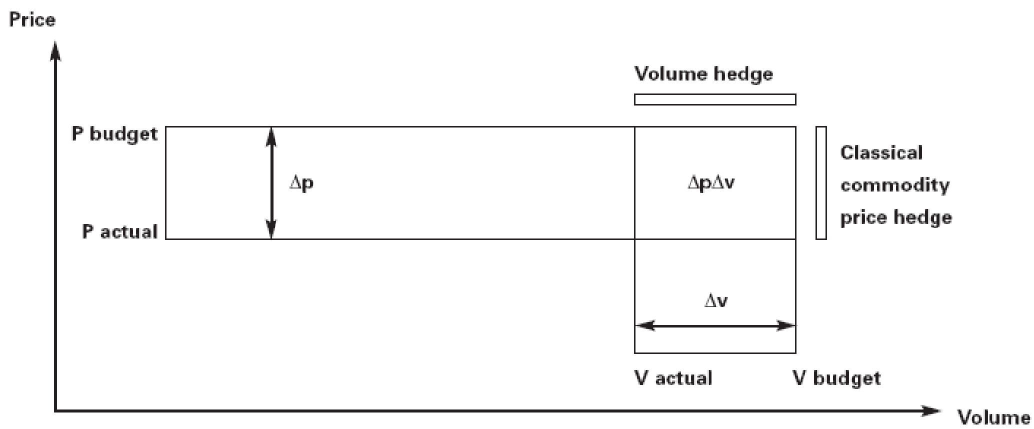
As highly structured financial products, weather derivatives are used in a dynamic management of weather risk and serve also as an instrument to diversify financial portfolios.

3. 1. Weather derivatives' specifics

The main difference between weather derivatives and traditional financial derivatives consists in no existence of a traded underlying instrument, on which would be weather derivatives based. While an underlying of traditional derivatives is traded on a spot market, it is obvious that this is not the case of weather.

Since weather itself is not priced, it is impossible to put a monetary value to its variations. Thus, on the contrary to traditional derivatives, weather derivatives are not used to hedge the price of an underlying. The primary objective of weather derivatives is to hedge volumetric risk, i.e. influence of changes in consumed volumes on a company's financial performance.

Figure 3: Cross-sectional hedge for the sale of weather-sensitive products



Source: Müller and Grandi (2000)

Regarding the idea of weather hedges, weather sensitive sectors are frequently exposed to great volatility even though prices remain unchanged[14]. Hence, the objective of hedging is in this case just volume compensation. In contrast, there are industries where exists high impact of demand on price and therefore application of both price and volumes hedging is necessary to create a quality hedge. Such a hedge is called cross-sectional.

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[13] Monthly and seasonal products are offered for Europe, Asia, Pacific or Canada, while even weekly for the U.S.

[14] To give a basic example, it would be the case of ice-cream sellers or swimming-pool runners.

According to Zeng (2000) or Mitu (2008), a weather derivative contract can be generally formulated by specifying several basic parameters listed below.

1) ***Reference weather station***. Almost all weather derivatives contracts are based upon one specified weather station, it may even happen that some use as a basis a combination of more stations.
2) ***Index*** defines when and how should be payments from the contract accomplished.
3) ***Term*** by which are defined days of beginning and termination of the contract.[15]
4) ***Structure***. As a weather derivative contract is based on standard financial derivatives' structures, its type (e.g. put, call, swap, collar etc.) has to be defined together with:
   a) Strike – specific threshold level when begin payments from the contract
   b) Tick – amount paid per one unit over the strike
   c) Cap (theoretical value) – maximum possible payment from the contract
5) ***Premium***. The buyer of a weather contract (option) pays a premium to the seller, usually between 10% and 20% of the theoretical amount of a contract.

3. 2. Weather derivatives vs. typical insurance

One might ask a question why to do not use common types of insurance. Since insurance contracts and weather derivatives are similar in many aspects, it may be confusing for a casual observer to find differences between these instruments.

It is relevant to say that weather derivatives have not emerged to replace traditional ways of insurance. Moreover, weather derivatives are not directly related to buyer's own financial costs as they are intended to profit from consequences of certain weather conditions. The payment is based on detected evolution of weather regardless of any impact on derivative's owner.

Insurance companies were involved in dealing with possible weather threats long time before the origin of weather risk market. And because weather derivatives are so specific and mostly have rather different intention, there is still a place for typical insurance contracts to stay in the market today. Both kinds of weather risk management techniques with their pros and cons serve to different purposes and it is not an exception that a company requires both of them to fulfil its specific needs.

According to Geyser (2004), highly specific weather derivatives differ from typical insurance contracts in several features listed below.

- Weather insurance contracts are designed to cover low-probability events with a high-risk such as hurricanes, storms, heavy rains or snowstorm blizzards, which may for example evoke

[15] Very frequent are contracts with the duration from November, 1 to March, 31 for winter and from May, 1 to September, 30 in case of summers. However, with growing flexibility in contracts' conditions has increased also the number of monthly or even weekly contracts.

cancellation of an outdoor sports or music event. In contrast, weather derivatives protect against higher probability events with lower risk as for example threat of warm winter or cool summer.

- Weather derivative's payout is designed to proportionally reflect the magnitude of a phenomenon while the payoff from a typical insurance contract has a form of one-term payment. In an insurance contract, the payout usually differs only slightly from the incurred loss. On the other hand, the fact that weather derivatives never properly match client's exposure is one of the most obvious restrictions to their expansion.
- When buying a typical insurance contract, an insured company must prove that suffered a financial loss in order to get the payment from insurance. On the other hand, if a weather event occurs, the payment from a weather derivative is made without proving anything. Therefore significant savings can be achieved on legal fees required to defend the payment.
- Since weather derivatives are traded securities, there is always a chance to re-sell these contracts that provides to companies increased flexibility in decision making. Based e.g. on updated weather forecasts, a company may decide to sell the derivative at some point of time before its maturity. When a company does not feel weather threat anymore, it may try to make some additional money on a derivative.
- Moral risk may be nearly removed in the case of weather derivatives as the reference is made to an index that none of counterparties can control. Since moral hazard is inherent in all insurance contracts, this feature also contributes to lower costs linked to weather derivatives.

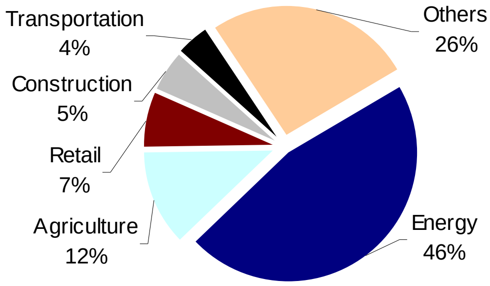
In a nutshell, since derivatives are less costly, do not require any demonstration of loss and provide protection from the uncertainty of changeable weather conditions, there exist strong reasons for giving priority to weather derivatives over typical kinds of insurance. Moreover, they might be used in both hedging against weather risk and making profits by speculation.

3. 3. Trading weather derivatives

In general, there exist to standard ways how to trade weather derivatives. On the primary market are provided weather hedges for end-users that face weather risk in their business, e.g. utility and construction companies or agricultures (see Figure 4). In the U.S., the majority of derivatives is traded at CME – that is still the largest weather derivatives market in the world. In the CME are provided both options and futures for a wide range of the U.S. and European cities.

Beside the primary markets, there exists the opportunity to trade weather derivatives on secondary markets. According to Sytsma and Thompson (2002), several counter-parties, among which belong insurance companies, large energy companies, commercial banks or energy merchants, may be willing to assume the weather risk exposure of an energy company. Their aim is straightforward - achieving arbitrage profits by trading weather derivatives. Each single transaction in the primary market generally gives birth to several transactions within the secondary market.

Figure 4: Usage of Weather Derivatives by Industrial Sectors (2006)



Source: WRMA Survey (2006)

In contrast to insurance market, a participant that would make profit in the case of cold winter may meet in the weather derivatives' market a different company that prefers a gentle winter. Hereafter if these parties conclude a deal, both of them co be protected from their unique weather risk.

Despite the fact that the usage of weather derivatives in Europe is still limited, the situation has changed in the recent past. Buckley et al. (2002) discussed three possible reasons why there has been slower take up of weather derivatives in Europe in comparison with the U.S.:

- lack of reliable, standardised and cheap weather data in Europe
- less substantial extreme variations in weather in Europe
- deregulation of energy markets

Likewise, also less frequent usage of air-conditioning in Europe could have helped.

Since the middle of 90's, the primary market participants in Europe have been energy traders and insurance companies. With the beginning of new millennium, the weather derivatives' market entered also banks in several countries[16] and apart from administratively complicated OTC trades, an efficient management of risk was provided also by exchange-traded contracts.

The first attempt to trade weather derivatives on standardized exchanges in Europe was made in 2001 when LIFFE[17] launched trading of three temperature-based weather indices in London, Paris and Berlin. However, this activity stopped after the acquisition by Euronext. The next significant attempt dates to 2005 when Powernext, an European energy exchange based in France launched together with Meteo France the quotation of national temperature indices for 9 European countries (including France, Italy, United Kingdom, Belgium, The Netherlands, Portugal, Spain and Switzerland) with the focus mainly on energy companies.

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[16] E.g. Societe Generale in France, Deutsche Bank in Germany or Banca Nazionale del Lavoro in Italy.
[17] London International Financial Futures and Options Exchange (LIFFE) is a futures exchange based in London.

The intention launched in 2005 further developed in 2007 by the development of Metnext – joint venture of Meteo-France and Euronext specialized in indices for weather risk management that even provides indices reflecting specific needs of individual firms with respect to their weather exposure (see Barrieu and Scaillet 2010).

There were concluded 34,068 contracts in Europe between April 2008 and March 2009 (according to internet pages of WRMA) that was about 9,000 contracts more than on the previous year. Nevertheless, the usage of weather derivatives in Europe is still of a low level.

3.4. Weather options

3.4.1. Degree days options

Weather derivatives as contracts whose payoffs depend on weather have several possible weather measures that can be used as their basis. Garman (2000) estimates that some 98% of all weather derivatives are based on principal temperature indices that are often used in the energy industry and traded as weather derivatives:

- Heating Degree Days (HDD)
- Cooling Degree Days (CDD)
- Cumulative Average Temperature (CAT)[18]

With flexibility in using these indices today is facilitated also the development of innovative hedging structures to manage a wide range of weather-related risks.

HDD and CDD are by their nature quantitative indices derived from daily temperature measurements, which are designed to reflect the demand for energy needed to heat or cool houses and factories. The idea of HDD consists in the fact that heating is usually required when temperature drops below some reference level and thus energy expenditure is needed. Heating or cooling requirements for a given subject at a specific geographical location are commonly considered to be directly proportional to the number of degree days. For detailed overview of weather indices in use see also Barrieu and Scaillet (2010) or Cao et al. (2004b).

HDD is defined as the number of degrees by which the daily average temperature is below some base temperature, while CDD express the number of degrees by which the daily average temperature is above this value. Mathematically expressed, daily HDD and CDD structures look as follows:

[18] CAT is used only rarely since as primary indices are generally perceived HDD and CDD.

(1) $$HDD = \max(0, T_{base} - T_{daily\_average})$$

(2) $$CDD = \max(0, T_{daily\_average} - T_{base})$$

The base approach in the energy sector, which has been previously used in numerous studies (see e.g. Cao et al. 2004a, Alaton et al. 2005 or Clemens et al. 2008), is to apply 18°C (= 65 degrees Fahrenheit) for HDD and 24°C (= 75 degrees Fahrenheit) for CDD as the base temperature.

Daily HDD and CDD are consequently accumulated over a period of time (usually of few months or whole season) that serves as an indicator of heating or cooling requirements for this period. Considering the interest of natural gas companies, increase in HDD corresponds with decreasing temperature, which is reflected in higher natural gas consumption. Since weather derivatives are applied for hedging of weather related risks over a long horizon, production of aggregate indices is needed. Campbell and Diebold (2005) demonstrate the importance of a cumulative HDD index (see equation (3)), which includes both nonlinear transformation of daily average temperature into HDD as well as further aggregation of daily indices because:

- weather derivatives are typically written on a cumulative sum of weather related outcomes
- November-March HDD contract is one of the most actively traded weather-related contracts and is also of a substantial interest to end users of weather models

(3) $$Cumulative\_HDD = \sum_{t=1}^{n} HDD_t = \sum_{t=1}^{n} \max(T_{base} - T_t, 0)$$

As we have already stated, the most commonly used weather derivatives are options, especially calls and puts[19] as well as their various combinations, e.g. collars[20]. With regard to intentions of particular hedges, a company generally decides on various option types shown in Table. Beside various purposes of particular options, this table introduces also simple drafts of payoffs that are generally based on the difference between the exercise and actual level of a weather index.

Table 1: Temperature options

option type	protection against	exercise when	payout
HDD call	overly cold winters	HDD > strike	tick*(HDD-strike)
HDD put	overly warm winters	HDD < strike	tick*(strike-HDD)
CDD call	overly hot summers	CDD > strike	tick*(CDD-strike)
CDD put	overly cold summers	CDD < strike	tick*(strike-CDD)

Source: Müller and Grandi (2000)

[19] Just to remind, general definition of a call option says that it gives the right to buy (call in) an asset and thus make a profit when the price of an underlying increases. On the contrary, a put option gives the holder the right to sell an underlying asset to the writer of an option.

[20] Collar enables a market player to minimize his hedging costs by buying a put and selling a call with the same strike price.

As we are primarily interested in fluctuations of natural gas consumption during winters, CDD are not considered in this paper as this index corresponds especially to requirements for cooling energy.

In spite of wide flexibility available in designing weather derivatives, basic attributes are common for the majority of contracts. Therefore several basic features have to be specified to determine the payoff from a HDD option. On the day following the end of a contract period, the payout from an option may be computed in compliance with equations (4) and (5).

- call option

(4) $$V = \min\left(\max\{0, (HDD - X)\} \cdot tick, cap\right)$$

- put option

(5) $$V = \min\left(\max\{0, (X - HDD)\} \cdot tick, cap\right)$$

where X means the strike level, HDD is an aggregate level of the index, Tick is the payment per one HDD and Cap is the maximum payment from an option.

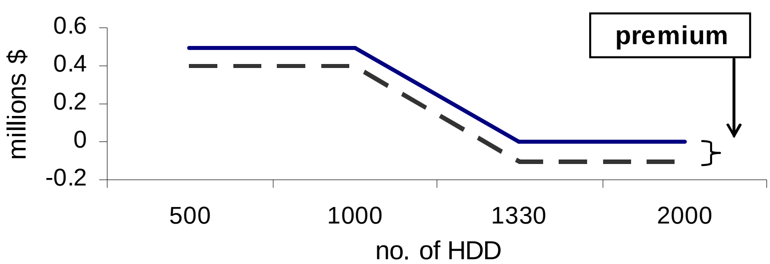
♦ ***Options used by companies trading natural gas***

Since revenues of natural gas companies decrease with warm weather especially during winters, these companies are primarily interested in hedging themselves against the case of lower number of HDD than the strike level. Therefore buying of a put HDD option is perceived to be an appropriate hedging strategy against warm weather.

Dutton (2002b) gives an illustrative example (see Figure 5) on the payoff structure of a long put option bought by Jefferson Gas as a protection against the risk of warm winter. The option was bought for the price (= premium) of $100,000 and with the following specifics:

- variable index – HDD
- cap - $500,000
- strike – 1,330 HDD
- rate of payment – $1,500/HDD

Figure 5: Payout diagram of a long put HDD option



Source: Dutton (2002b)

Consequently, the company would be paid up to the amount of $500,000 (the net revenue would reach $400,000) in the case of warm winter. On the other hand, if the cumulative number of HDD was higher than 1,330, the company would not be paid from the option and thus its net loss would be -$100,000 due to the premium payment.

3.4. 2. Pricing techniques

As the predictability of earnings is for companies highly valuable, one of the major advantages of weather derivatives consist in ability to dramatically reduce volatility in earnings. Nevertheless, an analysis of financial favourableness of hedging eventuality has to be always executed. Buckley et al. (2002) or Tindall (2006) list several techniques of pricing weather derivatives based on:

- regression analysis and correlations
- de-trended time series
- burning analysis
- Monte Carlo simulations
- seasonal weather forecasting

Companies could easily use meteorological services to assess weather derivatives, but as the reliability of long term weather forecasts is limited, pricing techniques are more in hands of statisticians than of climatologists.

♦ ***Black-Scholes model***

Since weather as an underlying of weather derivatives is a non-tradable asset, the possibility of using standard evaluation techniques is limited. Therefore *the Black-Scholes* model as a traditional way of pricing financial derivatives is not convenient Garman et al. (2000) list even 4 reasons why it is not appropriate to use the Black-Scholes.

1) Weather does not follow the "random walk" like asset prices do as they tend to revert back to their historical prices and thus fluctuate within relatively narrow bands.
2) Weather is rather predictable in the short-term while approximately random in the long-run. Hence it behaves different according to the length of the period.
3) In contrast to the standard Black-Scholes options, weather derivatives are frequently capped, i.e. there exists some maximum level of payoff.
4) Since the underlying of weather derivatives is not the price, pricing can not be free of economy risk aversion factors.

Since temperature is mean reverting, i.e. usually tends to revert to normal levels within a couple of days, any models using the random walk are inadequate for modelling temperature.

♦ ***Monte-Carlo simulations***

Other method is *Monte-Carlo simulations method* that incorporates a computer-based generation of random numbers that may be used in the construction of weather scenarios. It generally consists of simulation of numerous weather scenarios (e.g. based on HDDs) to determine payoffs of an instrument. Consequently, the fair price is the average of all possible payoffs approximately discounted to account for the time value of money.

♦ ***Burn analysis***

Nelken (2000) shows a different way of evaluating weather derivatives, which is frequently used also in the insurance industry and determines their financial impact with regard to past temperature. This method is generally known as *the burning cost method* or *burn analysis*. The aim of this approach is to answer the question: "*What would have been the average payoff of the option in the past X years?*" Therefore Nelken suggests the following procedure:

1) collect the historical weather data
2) convert to degree days
3) make some corrections
4) determine what would have been paid out from the option for every year in the past
5) make an average of these amounts

The main advantage of burn analysis in comparison with other methods is that it does not include any form of weather (temperature) forecasting. Since this procedure is highly logic and relatively easy to set up, it is quite common that market participants use this method in order to get the first notion about the fair price of an option.

4. Conclusion

Weather greatly affects economic performance of companies in many business areas, especially in the energy sector. Not only the short term extreme weather events such as hurricanes or heavy snow storms, but especially long term adverse weather conditions are often reflected in profits of companies in various businesses. For that reason, it is greatly in their interest to accurately predict sudden weather changes and to adopt arrangements to shield against their impacts.

In this paper we outlined major elements of weather risk and its management. We focused on the aspects of weather risk relevant for energy sector companies. Besides the discussion of major weather risk management techniques we also provided a brief overview of the development of weather risk management.

In order to protect themselves against financial consequences of weather risk, energy companies commonly undertake analyses of weather sensitivity of their businesses and of the most favourable ways of hedging. This unambiguously holds for example for companies trading natural gas since consumption of this commodity is highly affected by changeable weather, especially by temperature.

In this paper we provided basic information on so called weather derivatives, which are often employed in hedging against weather risk. The most frequently applied instruments by energy companies are HDD put options that serve especially as a protection against abnormally high temperatures in winter.

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