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Weather Risk in the Natural Gas Market

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Prohlášení

Prohlašuji, že jsem diplomovou práci vypracoval samostatně a použil pouze uvedené prameny a literaturu.

Declaration

Hereby I declare that I compiled this diploma thesis independently, using only the listed literature and sources.

Prague, 30 June 2009

Tomáš Vyležík

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Abstract

This thesis deals with the impact of weather on the natural gas market. We describe the development of the natural gas market in recent past and its current structure. Both these contingencies contributed to growing importance of hedging against weather risk today.

Consequently, with help of regression models we assess the dependency of Czech natural gas consumption on temperature, which is unambiguously the primary determinant of demand in the natural gas market.

Such an analysis frequently serves as the first indicator of the need for weather risk hedging, which is since the 90's commonly done with weather derivatives. Therefore we go through so called burn analysis that determines the fair price of an option with regard to past temperature measurements.

Keywords: natural gas, weather risk, regression model, weather derivatives

JEL class: C10, C20, G12

Abstrakt

Tato práce se zabývá vlivem počasí na trh se zemním plynem. Popisujeme vývoj trhu se zemním plynem v posledních letech i jeho současnou strukturu. Obojí přispělo k rostoucí důležitosti zajišťování proti riziku spojeném se změnami počasí v dnešní době.

Následně posuzujeme s pomocí regresních modelů závislost české spotřeby zemního plynu na teplotě, která je jednoznačně hlavním determinantem poptávky na trhu se zemním plynem.

Takováto analýza často slouží jako první indikátor potřeby zajištění rizika změny počasí, které je od devadesátých let obvykle prováděno za pomocí weather derivátů. Proto provádíme takzvanou "burn analýzu", která určuje cenu opce na základě teplotních měření z minulosti.

Klíčová slova: zemní plyn, riziko spojené se změnami počasí, regresní model, weather deriváty

JEL class: C10, C20, G12

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List of abbreviations

ACF	Autocorrelation function
CBOT	Chicago Board of Trade
CDD	Cooling Degree Days
CFO	Chief Executive Officer
CHMI	Czech Hydrometeorological Institute
CME	Chicago Mercantile Exchange
CORC	Cochrane-Orcutt iterative procedure
CSO	Czech Statistical Office
D-W	Durbin-Watson Statistics
EIA	Energy Information Administration
ERO	Energy Regulatory Office
EU	European Union
G	Daily gas consumption
GDP	Gross Domestic Product
GLS	Generalized Least Squares
GWh	Gigawatt Hour
HAC	Heteroskedasticity and Autocorrelation Consistent
HDD	Heating Degree Days
IEO	International Energy Outlook
LIFFE	London International Financial Futures and Options Exchange
LNG	Liquefied natural gas
MND	Moravské naftové doly, a.s.
MTI	Ministry of Industry and Trade
MVLUE	Minimum Variance Linear Unbiased Estimator
NGPA	Natural Gas Policy Act
NYMEX	New York Mercantile Exchange
OECD	Organisation for Economic Co-operation and Development
OLS	Ordinary Least Squares
OTC	Over-the-counter
PACF	Partial autocorrelation function
RWE TG	RWE Transgas a.s.
T	Daily average temperature
UK	United Kingdom
U.S.	United States of America
UNEP	United Nations Environment Programme
VIF	Variance Inflation Factor
WRMA	Weather Risk Management Association

♦ INTRODUCTION

Throughout history there have always existed many forces affecting economic life of the society. In this thesis we will focus on one the strongest that can not be physically influenced by anyone[1] and noticeably influences a broad range of activities: the power of weather. Weather highly influences our everyday life as it determines also what we do, wear or eat. When continuous discussions on global warming are nowadays more and more intensive, interest in the relationship between weather, environment and economies is increasing all over the world.

Weather can affect performance of different companies both in the short and long term. Not only extreme weather events such as hurricanes or heavy snow storms, but especially adverse weather conditions in the long term are usually reflected in profits of companies in various businesses. It is greatly in their interest to accurately predict sudden weather changes and adopt arrangements to shield from their impacts. Although there have been achieved some improvements in weather forecasting over the past years leading to its higher accuracy and consistency, the situation is still not ideal. Inaccurate forecasts may cause, beside daily inconveniences for ordinary life of people, also large financial losses in industry. There have been written thousands of studies trying to measure share of the economy vulnerable to weather. Taking into account the fact that weather impact varies with particular sectors of economy as well as with geographic regions, there is not easy to accurately assess weather impact.

Companies in a wide range of industries blame every year adverse weather conditions for their poor financial performance and failures to meet sales or profit

[1] Here I do not consider climate changes that would be for a long discussion.

targets. Since this had been repeating very regularly, own name “the weather excuse” for this feature appeared even in the Wall Street. But since more and more companies are today apprehensive that the weather usually implies a big-sized risk, it becomes very difficult to ignore it and blame weather for bad financial performance. A successful weather risk management program can mean the difference between profit and loss for many companies in different industries. In view of adverse financial effects of more frequent weather-related events, an increasing number of companies become interested in weather risk management.

At a glance, it is obvious that the energy sector belongs among industries that are greatly affected by weather. The impact of weather on the energy sector has been discussed in dozens of publications that cover up short term changes of atmospheric conditions as well as the influence of whole climate, i.e. variations of atmospheric parameters in the long term.

Among the most significant evidences of weather impact on the energy sector belong changes in heating and cooling requirements of households. In order to minimize effects of unfavourable outdoor temperatures, people decide to heat or cool in order to arrange a comfortable environment for living, what is highly reflected in consumption of both natural gas and electricity and consequently also in revenues of companies trading these commodities.

The intention of this diploma thesis is to assess threats linked to changeable weather. As the concept of protection against consequences of adverse weather has highly changed during the last decade, we are trying to apply these findings to the actual situation of the natural gas market in the Czech Republic.

First chapter is concerned with the theory of weather risk. We introduce the definition as well as the basic approach to these questions in the world. Moreover, one part is devoted also to basic knowledge of hedging against weather threats and history of the weather risk market.

Second chapter deals with the natural gas market and its historical context. We show basic situations when disturbances in the market, among which belong also adverse weather events, might appear. In addition, main contingencies in the Czech natural gas market are presented, what is absolutely fundamental for understanding of the situation in the market and therefore for further analysis of the impact of weather on this industry in the Czech Republic.

Third chapter is devoted to assessing of weather impact on daily gas sales in the Czech market. Development of temperature and daily gas consumption over eleven years as well as behaviour of these variables in particular months is demonstrated. Since the purpose of this thesis is to undertake an evaluation of the sensitivity of the Czech natural gas market to weather conditions, large dependency of natural gas sales on temperature is modelled with application of regression methods. As this dependency highly differs across various countries and its level commonly corresponds to the structure of natural gas users in particular markets, it is interesting to search for the results for the Czech Republic as there is no general size of the dependency in the world.

Since volatility in weather may bring high fluctuations in companies' revenues and profits, understanding and anticipation of weather impact on natural gas demand is essential for companies' managements and analysts to create accurate expectations. A precise model could also greatly help as an indicator whether to hedge against adverse weather or not.

In the last chapter, we describe the most frequent manners of protection against potential losses assigned to the risk of weather change. Potential hedging strategy with weather derivatives is suggested in the Czech natural gas market with help of methods that are often applied abroad.

1. 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.

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). What is more, 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”. Reflecting the role of weather in economy, the main reasons for costs incurred by weather come out here.

1. 1. Impact of weather on the economy

In this thesis 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[2] 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. 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*

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

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 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.[3]

Dutton (2002) 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

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

- the meaning of being sensitive

1. 1. 2. What is weather risk?

"Weather risk is the uncertainty in cash flow and earnings caused by weather volatility."

Jack Cogen*

Dutton (2002) 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 thesis 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 all companies to quantify all possible weather threats and hedge against them in the best way that they are able to do.

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

* Cogen, J. (1998): *What is Weather Risk?*

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.

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)

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.

♦ ***Risk on energy markets***

"Weather is a key driver for both electricity and natural gas demand."

Tom Ruck[*]

In energy markets weather influences chiefly the demand side. Nevertheless, when there are highly unfavourable weather conditions like a huge storm or even a

[*] Ruck, T. (2001): *Hedging Weather Risk For Improved Financial Performance.*

hurricane, also the supply side of the power network may be harmed as a commodity can not be delivered to customers.[4]

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***:[5] *"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***:[6] *"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***:[7] *"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."*

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.

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[4] It might be for example necessary to reduce for example electricity generation for some time to ensure safety of electricity users. What is more, also the electricity network or gas pipeline might be damaged during highly unpleasant weather even.

[5] Enbridge Inc. is a leader in energy transportation and distribution in North America.

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

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

1. 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: 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!

1. 2. History of weather risk management

"Weather risk markets are amongst the newest and most dynamic markets for financial risk transfers and include participants from a broad range of economic sectors such as energy, insurance, banking, agriculture, leisure and entertainment. Although the weather risk market is till very much based in the United States, new participants from Europe, Asia and Latin America are entering this market."

J. M. Geyser*

1. 2. 1. Way to the weather risk market

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.

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* Geyser, J. M. (2004): *Weather derivatives: Concept & application for their use in South Africa.*

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[8] proposed the concept of Heating Degree Days[9] 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.

1. 2. 2. Weather risk market's origin

The origin of the weather risk market dates back to the mid 90's, 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

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

earnings and thereupon transferring risks of adverse weather. This fact was soon stressed by the El Niňo[10] 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 90's.

To sum up, according to the Weather Risk Management Association[11] (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

[10] 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.

[11] 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]

- 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.

1. 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 [12] (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[13] while there were only twenty cities used in designing contracts four years earlier.

[12] 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.
[13] It included 24 cities throughout the U.S., 10 in Europe, 6 in Canada, 3 in Australia and 2 in Japan.

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)

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. What is more, 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. What is more, 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.

1. 3. Weather derivatives

"Since 1997, a financial strategy has emerged in the United States that allows companies to hedge weather-related risks with options based on weather variables. The instruments used to hedge weather risks are commonly called weather derivatives and are gaining wide acceptance in the energy industry as a primary mechanism for transferring weather risks to other parties."

Jan F. Dutton*

Since various uncertainties have crept into the new competitive natural gas market, either the need for financial derivatives appeared.[14] 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.

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* Dutton, J. F. (2002): *Weather Risk Mitigation at Jefferson Gas*.

[14] 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.

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 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[15]
- 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.

1. 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.

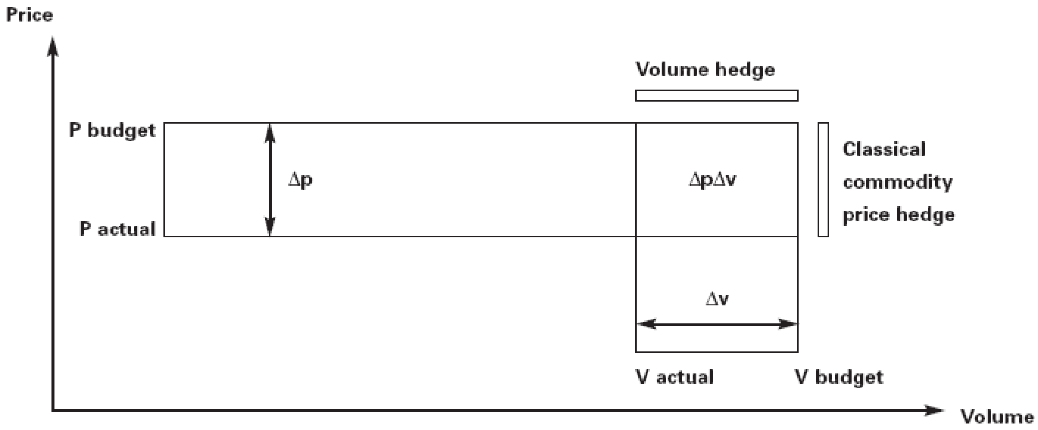
Regarding the idea of weather hedges, weather sensitive sectors are frequently exposed to great volatility even though prices remain unchanged[16]. Hence, the objective of hedging is in this case just volume compensation. In contrast, there are industries where exists high impact of demand on price and therefore application of

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

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

both price and volumes hedging is necessary to create a quality hedge. Such a hedge is called cross-sectional.

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



Source: Müller et al. (2000)

1. 3. 2. Weather derivatives vs. typical insurance

"The traditional market-based instruments for managing weather risk, e.g., insurance, are largely undeveloped and unavailable in most parts of the world. Given the growing interest in weather insurance markets, there are opportunities for innovation that have not been largely exploited."

J. M. Geyser*

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.

[*] Geyser, J. M. (2004): *Weather derivatives: Concept & application for their use in South Africa*.

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), pretty specific weather derivatives differ from typical insurance contracts in several features listed below.

1) 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 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.

2) 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.

3) 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.

4) 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.

5) 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.

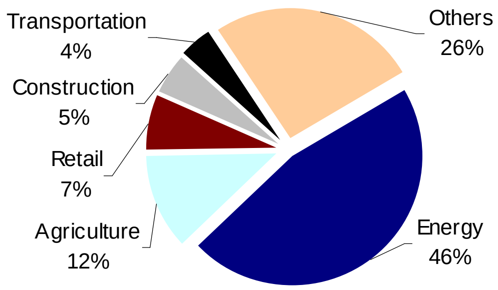
In a nutshell, since derivatives are less costly, do not require any demonstration of loss and provide protection from the uncertainty of changeable weather conditions, there exist strong reasons for giving priority to weather derivatives over typical kinds of insurance. What is more, they might be used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

1. 3. 3. Trading 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). There exist two primary exchanges providing standardized markets for trading of weather derivatives:

- CME – the largest weather derivatives market in the world. In the CME, both options and futures for a wide range of US and European cities are provided
- LIFFE[17] - where the contracts related to weather indices in London, Paris and Berlin started to be traded in 2001

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



Source: WRMA Survey (2006)

Another way of trading weather derivatives is on secondary markets where it is possible to find investment banks or trading houses specialized in these financial instruments. Their aim is straightforward - achieving arbitrage profits by trading

[17] London International Financial Futures and Options Exchange (LIFFE) is a futures exchange based in London.

weather derivatives. Each single transaction in the primary market generally gives birth to several transactions within the secondary market.

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.

An interesting fact is that usage of weather derivatives in Europe is still very limited. Buckley et al. (2002) discuss 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

What is more, also less frequent usage of air-conditioning in Europe could have helped.

Primary market participants in Europe have been since the middle of 90's energy traders and insurance companies. With the beginning of new millennium, the weather derivatives' market entered also banks in several countries.[18] Apart from administratively complicated OTC trades, an efficient management of risk is provided also by exchange-traded contracts.[19]

Despite the global fall in trading weather derivatives in the last year,[20] 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.

[18] E.g. Societe Generale in France, Deutsche Bank in Germany or Banca Nazionale del Lavoro in Italy.
[19] Already in 2001, LIFFE provided six types of contracts based on daily average temperature indices in London, Paris and Berlin on a monthly basis or for the whole winter season.
[20] For more info see http://www.energyrisk.com/public/showPage.html?page=860840.

2. NATURAL GAS MARKET

"Natural gas is believed by many to be the most important energy source for the future. The abundance of natural gas, worldwide as well as domestically, coupled with its environmental soundness and multiple applications across all sectors, means that natural gas will continue to play an increasingly important role in meeting demand for energy in the United States."

www.naturalgas.org[*]

Although the composition of natural gas can widely vary, it is a mixture of hydrocarbons that remain in the gas phase at standard temperature and pressure.[21] It is a colourless, odourless, tasteless and shapeless gas that is lighter than air, primary formed by methane with other standard components such as ethane, propane, butane, pentane etc. For precautionary reasons, a chemical odorant is added to natural gas to be smelled in case of a leak. As a combustible gas it gives off a great deal of energy when burning. Unlike other fossil fuels natural gas burns cleanly and emits lower levels of potentially harmful by-products into the air.

As global natural gas consumption has been steadily rising throughout 20th century (see Figure 5), the importance of natural gas as a clean and low-cost fuel helped in the 90's to further gross up of investments in facilities using natural gas, that declares also the fact that the vast majority of new electricity generation capacity build in the U.S. in the 90's is natural-gas fired.

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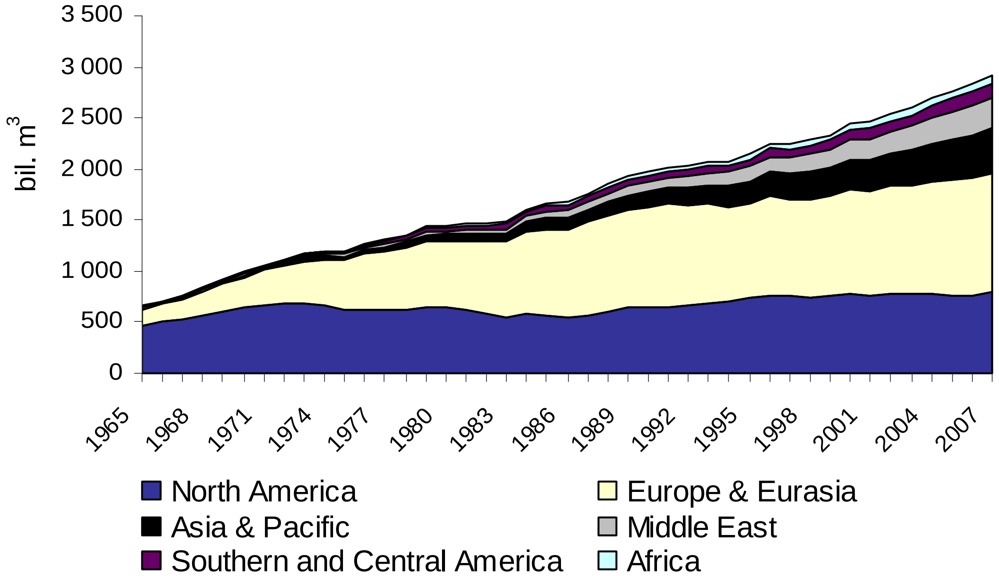
[*] Available at: http://www.naturalgas.org/business/demand.asp.

[21] This definition means weather conditions with the temperature of 20°C and atmospheric pressure.

Figure 5: World's natural gas consumption since 1965



Source: BP Statistical Review of World Energy June 2008

Energy Information Administration[22] (EIA) expects[23] *"… natural gas to replace oil wherever possible. Moreover, because natural gas combustion produces less carbon dioxide than coal or petroleum products, governments may encourage its use to displace the other fossil fuels as national or regional plans to reduce greenhouse gas emissions begin to be implemented."* Consequently, global consumption of natural gas is projected to grow by 52% between 2005 and 2030.

Concerning continuing trend of growing natural gas consumption, economies all over the world will become, and have been actually becoming even in recent past, more vulnerable to market disruptions. Therefore business adjustments, e.g. in the form of hedging with financial derivatives, have to be done to avert potential financial losses.

Nowadays in highly energetically dependent world, natural gas as an energy source has elevated to an extreme level of importance with usage in four main areas:

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[22] EIA is an independent agency within the U.S. Department of Energy that develops surveys, collects energy data on reserves, production, consumption, distribution, prices, technology or related information, and does analytical and modelling analyses of energy issues. Furthermore, the EIA publishes both long- and short- term energy forecasts.

[23] EIA (2008): *International Energy Outlook 2008*.

- The principal use of natural gas is in ***production of steel, glass, plastics or other products***.
- Through the use of gas and steam turbines, it is also a source for ***electricity generation***. Since natural gas produces less carbon dioxide when burning, it is estimated to be widely spread in electricity power generation in future.
- It is widely used as a ***heating source in manufactories***.
- And finally, what almost everybody knows from its own house, are deliveries of natural gas for heating and cooking in ***residential domestic use***.

But there are also other and more recent alternatives of usage as for example:

- compressed natural gas is a cleaner alternative to typical automobile fuels – gasoline and diesel
- it can be also used to produce hydrogen which is valuable in the chemical industry, oil refineries and hydrogen vehicles
- other possible usage is in fertilizer production

With regard to weather sensitivity, it is straightforward that especially the dimension of residential heating and electricity generation is highly weather dependent. In conjunction with superior needs for manufacture heating during winters, absolute majority of the natural gas consumption is perceived as weather dependent.

2. 1. Market characteristics

Nowadays, there are two main forces shaping the European gas market:

- growing dependency on non European Union suppliers
- continuing liberalization of the European market

Both of them have highly affected the supply side of the European gas market in the last decade. Apart from these forces, the natural gas market is determined by other phenomenon, on the supply as well as demand side, which pressure companies in gas business to adapt to the actual situation in the market of the 21st century.

It is possible to distinguish sources of risks in the natural gas market, or generally in energy markets, with regard to their position; i.e. whether they lie on the supply, or demand side. With pressure on decreasing margins in the market and with the majority of sales being highly contingent on weather, the need of assuring coverage against possible risks will be increasingly important for companies in the gas business.

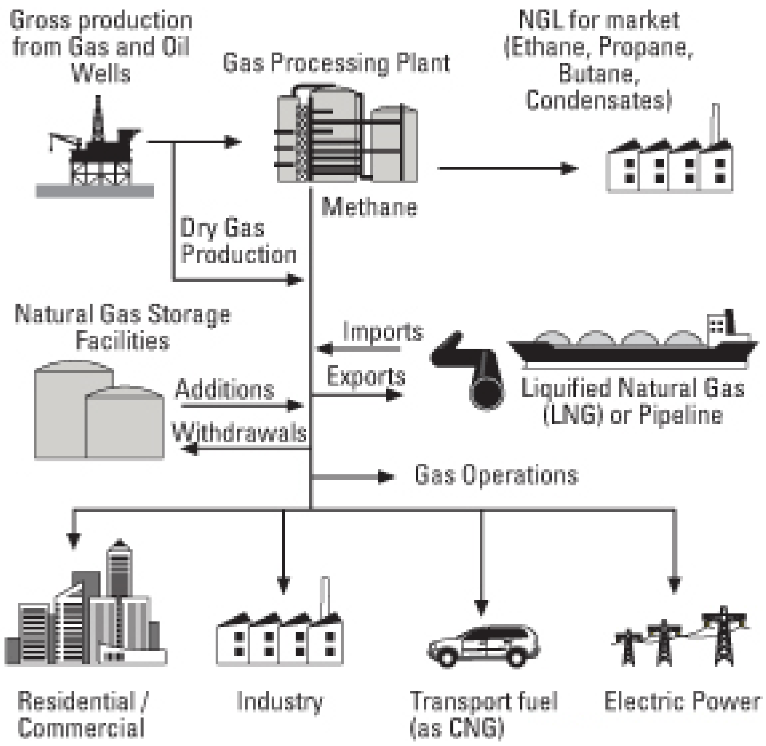
2. 1. 1. Deliveries of natural gas

Natural gas supply stream, when the commodity is flowing from wells through pipelines as far as to burning places, never stops. Whole natural gas market functions as a uniform organism where all particular participants, functions and activities are in close connection in two segments:

1) exploration and production
2) distribution and sales

In order to identify all possible sources of risk in the natural gas supply chain, let us now quickly go through Figure 6, where are components of this industry described more closely.

Figure 6: Natural gas flow from the well



Source: www.natgas.info[24]

[24] See http://www.natgas.info/html/gaspipelines.html.

- *Wellhead* - when a new natural gas field is discovered or there is associated gas in a crude oil reservoir, a production company drills for and extracts the crude commodity. The wellhead, into which the gas emerges when it comes up from the underground, funnels and controls the flow of gas to the surface.
- *Gas processing* - each wellhead is connected to the gathering system, a small-diameter pipeline system transporting gas to a central location, where is situated all necessary equipment required for delivering of a clean and saleable product. Volumes' processing can be characterized by extracting liquids and other by-products[25] in order to prepare a dry gas stream that meets industry standards for transportation through high-pressure pipelines.
- *Transport* - on the other side of the processing facility is located the receipt point where is the gas received by a larger-diameter pipeline, called the mainline. The natural gas is by these high-pressure pipelines commonly transported from regions of extraction into market areas and then to industrial end users, storage areas and local distribution companies. Because natural gas flows only from a high pressure area to an area of low pressure, compressor stations are set up along the mainline.
- *Liquefied natural gas (LNG)* – natural gas that is temporarily converted to liquid for ease of storage and transport is a special category. For example, this imported gas from overseas increases the supply in the U.S. by 3%. Of course, this can not be the case of the Czech Republic.
- *Storage* – natural gas system is not designed to produce and transport the full amount of natural gas demanded during peak-demand periods. Storage facilities are located along pipelines between gathering and market areas, mostly closer to final customers, to help in balancing receipts and deliveries of the commodity. The natural gas may be injected and withdrawn again to satisfy consumers' needs during a peak demand period, e.g. during cold winter days.

[25] There exists a specific active market for some of the by-products such as propane or butane.

- *Local distribution company (LDC)* – usually owns and operates the network of pipes that carry natural gas from high-pressure pipes to end customers.
- *End customers* – mostly residential, industrial, commercial and ensuring electric power generation that are located at the end of pipeline systems.

Apart from all previously mentioned elements of the natural gas market and companies carrying given services, there is also other group of market participants that partially shapes the whole structure of the market - marketing companies. These companies, which are able to provide a various range of services, e.g. selling supplies or securing administrative services, are looking for profitable opportunities along a pipeline. Their most widely known role consists in functioning as ***trading companies*** that are buying and selling natural gas for creating a profit.

Many of trading companies that operate also as marketing companies may be, besides making a spread, i.e. margin as a difference between buy and sell prices, even seeking for other profitable occasions. With progressing deregulation, there have appeared many new market participants, which for example try to make profits on financial transactions. Also producers or local distribution companies are trying to take an advantage of these conveniences. Increasing number of market participants bearing on margins' decrease force companies to exploit all opportunities to sustain their profitable functioning.

2. 1. 2. Historical context - deregulation

In the middle of the 20th century, the natural gas industry was believed all over the world to be a "natural monopoly". As governments were afraid of setting unreasonably high prices for customers, regulation of this industry was established.[26] But the structure of whole industry has gone through significant changes during last decades since it was hit by the process of deregulation and liberalization. Hence, the market left its limited flexibility with just few options for natural gas deliveries. In the following paragraphs, situation in the U.S. is employed as a benchmark case to show how this process looks like.

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[26] Regulation of the natural gas market started in 1938 in the U.S.

♦ ***Regulated market***

In the natural gas market used to be a structure where exploration, production or trading companies were transporting natural gas to local distributors, which were selling the commodity mostly to end-customers. All prices were within this chain regulated by state governments; starting with prices of transport and ending with the prices for which traders were selling the commodity to regional distributors or even end-customers.

Structure of whole natural gas industry with regulated prices and established monopoly structures was very explicit with a very little space for competition and incentives to innovations and improvement of services. As an intention of various regulations was to ensure adequate supplies for customers at a fair price, sales were subject to government oversight at every single step of the way from a well-head to a burner-tip. Natural gas demand curve was highly inelastic. The basic presumption was that whole supply should be all the time able to cover demand at each location. This was a target that large state companies and monopolies with exclusive supply concession needed to meet.

As risks in the natural gas market have always lied primarily on the demand side, it was the role of national governments before liberalization to ensure that flexibility in gas production, which ensures the supply side to match the demand within a level that is not volatile too much, would be permanently sufficient. But within the U.S. this situation led in the end even to mismatch between the natural gas supply and demand, evoking shortages in the 70s and surpluses in the 80s. It was obvious that the structure of the natural gas market had to change. The regulation was no longer doing its job and competition in a free market was considered to be an alternative.

NYMEX (1998) states that before deregulation, lack of incentives to drill for new supplies and reliable, readily accessible transportation both obstructed growth of the gas industry. The level of rigid regulation strongly declares also the fact that the liberalization of the natural gas market in the U.S., which started in 1978, resulted in a more significant increase in the production of natural gas than one would expect.

Furthermore, a large extent for development of the market in natural gas futures and options was exploited by liberalization.

- ***Deregulation process***

Market structure has completely reversed during the recent past, mainly in the U.S. As a result, prices are no longer regulated and since the price of natural gas fully depends on interactions of supply and demand, the market is much more open to competition and therefore is functioning like other commodity markets. Hence, the market is accessible to opportunities as well as risks of competition.

Conditions in the natural gas industry were changing throughout the second half of the 20th century also due to the increasing importance of this commodity for the society. In the end, the idea of deregulation with market based prices and competition emerged in the 80’s and 90’s. With shortages at the supply side in the U.S. reaching their peak in November 1978, the U.S. Congress enacted the Natural Gas Policy Act (NGPA) aimed at abolishing of the American natural gas market regulation to:

- create a single national natural gas market
- equalize supply with demand
- allow market forces to establish the price on the market

Continuing gas market liberalization was ensured settlement of binding antitrust policy on volumes flowing into transport network and volumes sold to final costumers. This resulted in a fall of selling margins as new competitors were finally allowed to enter the market. With further progress in liberalization, major traders in the market faced increasingly higher competitive pressure that led to heightened stress on further margins’ fall.

On the other hand, although the market may be fully liberalized, there could be still needed a national authority holding surveillance power on pricing. Its decision may limit the ability to increase costs for customers, chiefly tendencies of main players in the market to sell the commodity for inadequately high price to residential and commercial users.

♦ ***Consequences***

Lower prices for customers and new discoveries of natural gas fields were achieved as a consequence of deregulation in the U.S. Opening of the industry and avoidance from strict regulation brought also increased efficiency and motivation to technological improvements. Despite the fact that looking for new natural gas fields brings companies to hardly attainable places to meet increased demand requirements, ways to extract the commodity are today more efficient, cheap, and easy than before.

As price variations are common in deregulated markets, both producers and consumers react to these changes rationally. Since there are reasons, mostly technological, that force producers to continue producing at the same level even in a period of lower price, also consumers do not frantically change their demand with just a little change in prices.

2. 1. 3. Natural gas supply and demand

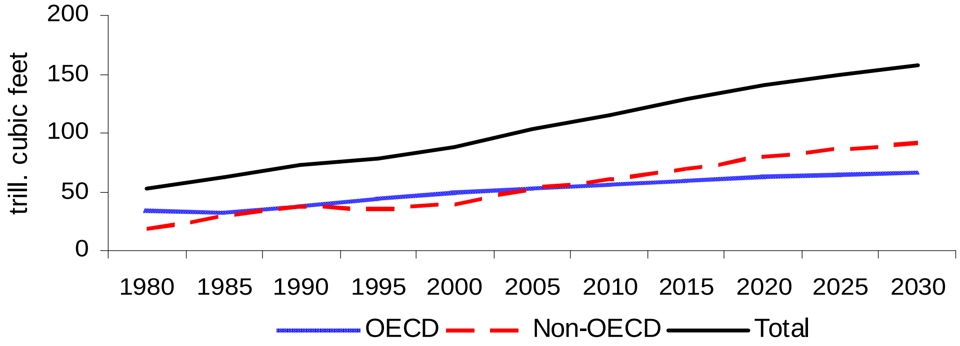
In order to ensure non-problematic commodity deliveries, the natural gas market heavily relies on resources available to extraction. As a petroleum by-product, natural gas is usually found wherever is located also crude oil, what means in reservoirs deeply under the land or oceans' floor.[27] According to the United States Energy Information Administration[28] (EIA), global natural gas reserves reached 6.168 trillion cubic feet by the beginning of 2008, what is sufficient enough cover world's demand in the near future without any troubles.[29]

The structure of natural gas supply and its determinants are very straightforward. Beside demand and occasional natural disasters, there is in general one other factor essentially affecting supply – price. Producers have with higher natural gas price more incentives to search for new reserves. To do not have maintenance and production costs exceeding sales revenues, it makes sense that with

[27] Compared with oil, natural gas is considered to be easier to drill.
[28] EIA, established in 1977 by the U.S. Congress, is the independent statistical agency within the U.S. Department of Energy. It should provide policy-independent data, forecasts, and analyses on energy markets.
[29] EIA (2008): *International Energy Outlook 2008*.

falling prices there comes up the producers' tendency to close down the least profitable wells.

Figure 7: Global natural gas consumption forecast until 2030



Source: International Energy Outlook 2008

Global natural gas demand continues to grow with power generation as the primary driver in the U.S. and Europe. Considering dependencies in the market, growing natural gas demand (as it is forecasted in Figure 7) should logically lead to higher commodity prices as well as natural gas supply.

Demand for natural gas has always been cyclical as it changes with various periods of a year as well as with different seasons. Because the primary driver of demand has always been the need for residential and commercial heating, demand is clearly highest during the coldest months of a year, reaching its peaks in January or February, whereas lowest in the warm summer moths as June and August. The situation has recently changed with enlarged usage of natural gas for electricity generation. Increased demand for electricity due to residential and commercial cooling leads to the higher requirements on supplies of natural gas even during warmer months. Hence, there is today milder decrease in natural gas demand during summer months than what used to be.

♦ ***Determinants of the natural gas demand***

Beside the natural gas consumption cycle, there are three main drivers determining the short term demand, which may push the demand to be far from long term predictions.

1) ***State of economy*** may have a considerable effect particularly on the natural gas demand of industrial consumers in the short-term. In a period of economic expansion, demand for natural gas usually rises due to the growing industrial production. On the other hand, when the economy passes through bad times as it is actual situation in the world, demand for natural gas decreases mainly due to restricted consumption of industrial plants or even because of closing down some of manufactories.

2) ***Price of natural gas***, which is created by interactions of supply and demand, can either affect the demand in a reverse way. Whenever the price is too high, there always exist some consumers, particularly industrial and power plants, which are able to switch from natural gas to other types of fuels.[30] Whenever there is a significant upward swing in the natural gas price, companies selling other fuels (electricity, coal, etc.) may compete and try to entice away customers from natural gas traders by setting a more feasible price.

In spite of the fact that residential customers may immediately adjust their thermostats when they are not interested in paying excessively high prices, natural gas demand is firstly influenced by the number of customers that are loosing interest in the commodity. This is a long term process as home-owners or commercial managers usually have to be convinced that the change of fuels will bring permanent and favourable alternation. Nevertheless, commercial customers with large consumption and possibility of a dual-fuel capacity may be an exception and therefore decide on switching fuels even in shorter time.

3) ***Weather*** is the third driver affecting natural gas demand. Since it may cause shifts in demand during any particular season, for example consumption's peak during an extremely cold winter may be more pronounced than usually due to weather.

[30] For example switching to cheaper coal leads to lower demand for natural gas since especially relative prices between fuels, mainly in the long term, play a meaningful role.

2. 1. 4. Market disturbances

"… factors which influence gas demand include the gas price, the impact of energy conservation measures, general economic growth and in particular the weather, which is the main determinant of short term variations in gas demand."

Energy Markets Outlook*

Problems on the supply side might have various reasons. Apart from threats of natural disasters, there is a high chance of technical failure or political disputes that influence the natural gas market. Notwithstanding that the stability of the European gas market was previously tested on a number of occasions, there were never experienced any large disturbances in supply until 2009.

Before 2009, supply side problems were perceived as relatively minor threats. All major cases in the history of the European gas system were solved with help of storage facilities or other pipeline systems without any significant problems. De Joode et al. (2005) list several widely known problems with the European natural gas supply over the last twenty years:

- Strike among offshore workers in the United Kingdom and Norway in 1986 caused a loss of approximately quarter of total Norwegian supplies for several days.
- Bomb attack on the Trans-Mediterranean pipeline in Algeria in 1997. Because of the use of gas storage and alternative suppliers, there was not any significant impact on the market.
- As Ukraine demanded for crossing its area a transit fee by means of unauthorized diversions, it caused disturbances in the transit of natural gas from Russia few years ago. Even in this case did not arise any serious problems in Europe because of other opportunities to substitute the withdrawn supply.
- Transit difficulties in Turkey caused some physical shortages in 1994 and 1995.

* Department for Business, Enterprise & Regulatory Reform (2007): *Energy Market Outlook*.

Aside from Europe, there happened several disruptions also in parts of the world. The largest American one called the El Paso natural gas disruption occurred in 2000 in New Mexico. Also in this case were markets independently able to avoid severe gas shortages.

After a long time when supply in the European gas market, which the Czech market is a part of, had not been hit by any significant disruption, the "Russia-Ukraine gas dispute" appeared with the beginning of 2009.

When Europe's gas dependency on Russia is so significant that some countries are reliant upon Russia even with 100% of their total natural gas supply, it may occur that problems on the supply side in the near future will arise especially due to similar political reasons.

Table 1: European countries' gas imports from Russia in 2004

country	from Russia (bil. cub. ft.)	% of domestic consumption	country	from Russia (bil. cub. ft.)	% of domestic consumption
Germany	1 290	39	Ukraine	850	35
Italy	855	31	Belarus	698	99
Turkey	506	65	Hungary	318	64
France	406	24	Czech Rep.	253	77
Austria	212	69	Slovakia	226	99
Poland	212	43	Poland	212	43
Netherlands	94	6	Finland	163	98
Greece	78	82	Romania	138	22
Sweden	39	< 0.5	Lithuania	103	100
Belgium	7	1	Bulgaria	99	99
Denmark	< 0.5	< 0.5	Moldova	77	100
Ireland	< 0.5	< 0.5	Latvia	62	100
Portugal	< 0.5	< 0.5	Georgia	39	100
Spain	< 0.5	< 0.5	Estonia	34	100
UK	< 0.5	< 0.5	Slovenia	20	52

Source: Gelb, B. A. (2007)

The ability to deal with any supply side disturbances is today fully dependent on available alternative sources: usage of another pipeline, sufficient storage surplus or transport capacity in the system. When a gas-line breaks down or is cut off (e.g. due to political disputes), different source of natural gas or just another pipeline from the same source is usually used to cover the missing supply what should not be a problem today. In addition, technical failures are today usually quite easy to repair and thus the commodity is flowing again through the same pipeline within a couple of hours.

Since there were no big troubles in the past with natural gas supply in the European market, it seems that major risks have been related to demand fluctuations and the ability of supply to cope with them. In addition changeable prices, there are several other reasons affecting the level of demand for natural gas among which weather is of the highest importance.

2. 2. Czech natural gas market

In this part, we describe the situation in the Czech gas market and market structure with all contingencies.

2. 2. 1. Liberalization

The situation in the Czech natural gas market started to change few years ago as European Union's (EU) directive no. 2003/55/ES, which is valid since 2004, installed an obligation of EU-member countries to implement remedies to improve the situation in the natural gas market. As we have already mentioned the American natural gas market and its liberalized environment, the intention of EU is to get successively closer to the situation in the U.S through the free option to choose a supplier by wholesale customers (since 2004) as well as households (since 2007). At the same time, legal unbundling of runners of supply stream is demanded,[31] the role of national regulatory offices is reinforced and the public service commitment is assured. Expected consequences of liberalized EU natural gas market are:

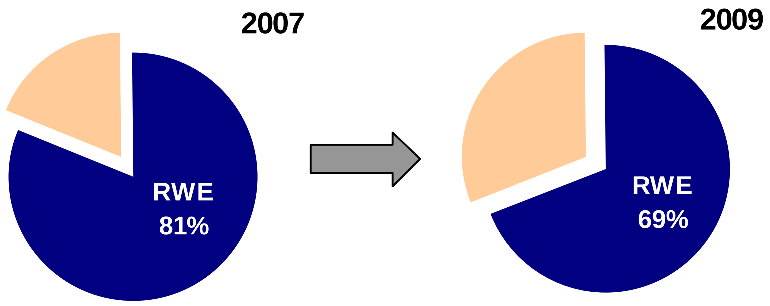
- lower prices
- admission of new market participants
- increased competitiveness
- enhanced effectiveness
- higher level of provided services

[31] Particular companies in this stream are not the same legal objects what in the Czech natural gas market means that RWE TG, the main supplier in the market, is permitted to run the distribution network at the same time etc.

- higher security of supplies

Until January 1, 2005 the Energy Regulatory Office (ERO) limited operators of transit and distribution networks in the Czech Republic and was setting tariffs for the entrance to the network. All deliveries were done through RWE Transgas, a.s. (RWE TG) with no change for customers to change the supplier. Sequential liberalization started in 2005. Based on the law no. 458/2000 Sb., the Czech natural gas market is since April 2007 administratively fully opened to competition in supplies to end-customers.

Figure 8: Dominant player's market share (sales to end-customers)



Source: RWE TG[32]

Despite the fact that in the Czech Republic have emerged about 60 new traders since the beginning of liberalization,[33] there are just 8 really significant new traders in the market. Although these traders have so far taken just a limited market share, it was enough to result during a relatively short period in fall of market share of the main market player, RWE Group[34] (see Figure 7). Since end customers were allowed to change their supplier, RWE Group has lost 12% of its share in the market for end

[32] Presentations: *RWE Group in the Czech Republic in 2007* and *RWE Group in the Czech Republic in 2008*.
[33] According to the Czech Republic's *Report on the Security of Natural Gas Supplies in 2007*, there are in total 88 companies holding the permission to trade natural gas. In the retail market there are just 8 traders where each is supplying gas at least to 90 ths. customers.
[34] RWE Group in the Czech Republic operates in both wholesale market via RWE Transgas, a.s. and market for end-customers via its regional gas companies.

customers,[35] chiefly due to tough competition in the market for main industrial customers.

Price, as the main motive to the change of a supplier, is logically in the background of fall in the market share of the dominant player. As the price of natural gas in the Czech liberalized market consists of a regulated component set by ERO once a year,[36] price for structuring (storage), non-regulated component of price and a margin, it is straightforward that the pressure on margins' lessening and consequently lower profits of gas traders is much higher than before 2007.

2. 2. 2. Czech natural gas supply

As there has not been any failure of gas deliveries since 1990, the Czech natural gas market is, despite the fact that only some 1% of resources is indigenous[37], characterized by a high level of security of supplies. Based on the data from 2007, natural gas is delivered to the Czech Republic from two main sources[38]:

- Russian federation (78%)
- Norway (22%)

Since imports of natural gas are crucial for the Czech Republic, long term import contracts belong to basic arrangements that contribute to the stability of the market. Given the contracts of RWE TG with its Russian and Norwegian suppliers, it is possible to import 11.4 bil. m^3 of the commodity yearly. According to the contract of another trader in the Czech market - VEMEX, s.r.o. with Gazprom, total possible volumes of natural gas that could be imported to the country reach yearly even 12 bil. m^3.

Considering the National Energetic Conception of the Czech Republic (2004) and also this year's dispute of Ukraine and Russia, the goal of the country is to cut

[35] It is necessary to distinguish between the market for end-customers, where RWE holds via its regional distribution companies' share of 69%, and wholesale market, where RWE holds 86.5% in 2009 mainly due to sales to Pražská plynárenská and E.ON.
[36] That in gas-business terminology embraces transport and distribution.
[37] With the main domestic supplier - Moravské naftové doly, a.s. (MND) in southern Moravia and marginally OKD Paskov in northern Moravia.
[38] Insignificant volumes (0.02%) are imported also from Germany.

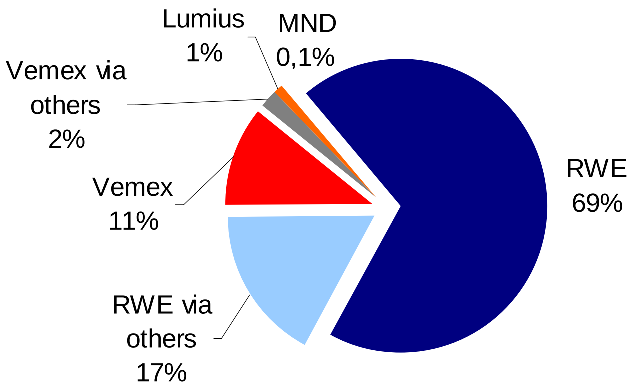
dependency on imports from Russia with several new gas lines that are being currently discussed within Europe.

Beside natural gas imports, there is obvious one more important factor significantly participating on gas supplies – gas storage. In order to assure non-problematic deliveries during periods with highest consumption requirements or to cover blackouts in imports as it happened in January 2009, the commodity flows into pipelines also from underground storages. Satisfactory storage space in the Czech Republic is one of the main reasons why there have not happened any disruptions in supplies during the last twenty years. Their importance underwrites also the fact that even during the warm year of 2008, there was extracted 1,830 mil. m^3 from underground storages, what equals to 21% of total yearly consumption in the Czech Republic.[39]

♦ ***Natural gas suppliers***

As the market with assured non-problematic deliveries is nowadays opened to competition, there are several main players in the market engaged in deliveries of the commodity to customers (see Figure 9). As competition in the market becomes tougher, companies' profits are threatened what is also the case of the market leader.

Figure 9: Czech natural gas market in 2009



Source: RWE TG and Balance Centre

[39] Similar volumes were also injected into storages mainly to balance supplies with demand requirements in the next heating season.

There are 4 participants in the Czech wholesale market (having assured their own gas deliveries) and several others in the market for end-customers, e.g. Pražská plynárenská or E.ON, which are buying the commodity from two main traders – RWE Transgas, a.s. and Vemex, s.r.o and consequently provide supplies to end-customers.

2. 2. 3. Czech natural gas demand

"Natural gas consumption in the Czech Republic has been at a standstill since 1997 and in the previous years there happened even a mild fall in consumption. An exception is year 2007 when there was higher fall in natural gas consumption due to unusually high temperature during the heating season."

Ministry of Industry and Trade*

Natural gas consumption was steadily decreasing between 2003 and 2007. This trend stopped in 2008 when consumption reached 8,685 mil. m3, what was 0.4% more than in the previous year. Both Balance centre[40] (BC) and MIT consider above average temperatures in this period as a crucial reason for low consumption. As it is obvious from

Figure 10, natural gas consumption is influenced whenever there is a significant difference from yearly normal temperature.[41]

Nevertheless, consumption does not have to be far from expected values only due to temperature as there are other effects having an impact on consumption, e.g. economic cycle. Figure 11 transparently shows development of both real consumption and its values adjusted to the normal temperature.[42]

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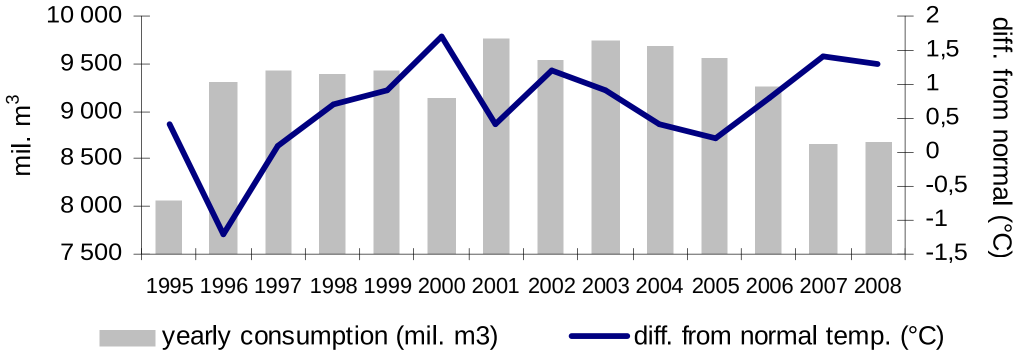
* MIT (2008): *Zpráva České republiky o bezpečnosti dodávek zemního plynu za rok 2007.*

[40] Balance centre (BC) – in Czech "Bilanční centrum" is responsible for processing the data on the Czech natural gas market and handing them over to MIT, ERO and Czech Statistical Office (CSO).

[41] I.e. as the average temperature in 1996 was 1.2% below normal, meaningful increase in gas consumption occurred. On the other hand, highest above average yearly temperatures in 2000, 2007 and 2008 resulted in falls in gas consumption.

[42] Normal temperature is a 30-years average of daily temperatures announced by Czech Hydrometeorological Institute.

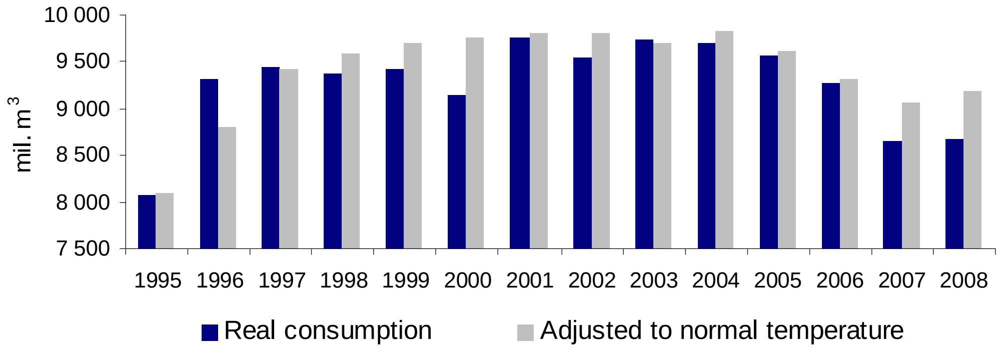
Figure 10: Yearly consumption and normal temperature



Source: BC

Even in the adjusted scenario is apparent decreasing trend in consumption since 2004 that is induced mainly by increasing prices and consequent tendency of customers to save money by lower consumption. Nevertheless, the impact of weather unambiguously displays the comparison with real consumption in a particular year as there occur big differences between adjusted and real consumption at the same time temperature highly differs from normal.

Figure 11: Real consumption vs. adjusted to temperature



Source: BC

♦ ***Customer segments***

There exist following four consumer segments (given their yearly consumption), according to gas business terminology, which participate on republic's overall consumption:

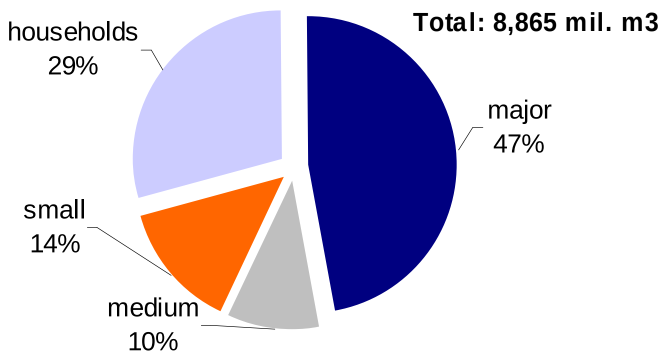
1) households

2) small customers (yearly consumption up to 630 MWh)

3) medium customers (up to 4,200 MWh)

4) major customers (over 4,200 MWh a year)

Figure 12: Customer segments in 2008

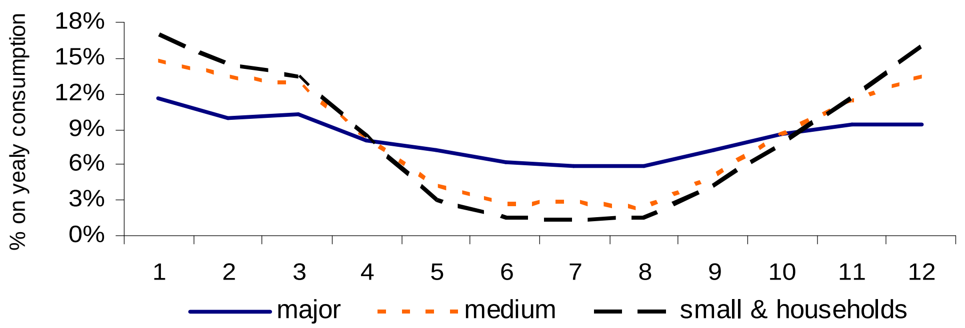


Source: BC

Since various segments are differently susceptible to weather changes, they comprise a significant feature in planning yearly consumption and especially its monthly structure. Given monthly consumptions of particular customer segments, it is obvious that consumptions of all particular groups are influenced by temperature.[43]

With regard to Figure 13, it is obvious that there is not such a significant fall in consumption of major customers during summer as in the case of small customers and households, which offtake the majority of their yearly volumes during winters.

Figure 13: Monthly consumption of customer segments in 2008

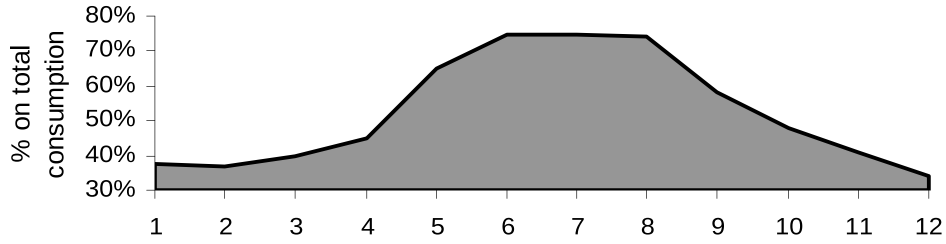


Source: BC

[43] Monthly consumption structure of small customers and households was in 2008 approximately identical. Therefore I merged them in Figure 13.

Small industrial customers and households, which comprise 43% share of yearly consumption in the Czech Republic and use the commodity principally for heating purposes, almost stop off-taking natural gas during summer. On the other hand, major customers that often use the commodity directly in production process, keep a relatively high level of consumption even during warm days. It is the segment of major customers who contributes the most to so called "base-load demand" which is kept at some level even during the warmest days in summer (see Figure 14).[44]

Figure 14: Share of major customers on total monthly consumption in 2008



Source: BC

A company has to be always aware of the structure of its portfolio of customers when considering impact of weather on natural gas consumption. Therefore one of initial activities of a company should be such analysis leading to identification of shares of particular customer segments on whole consumption and their resistance against weather changes. Considering the situation in the Czech Republic, it is obvious that at least 43% of end customers (households and small customers) are heavily susceptible to changes in temperature, what is very obvious from their summer consumption habits. Moreover, these customers are generally able to modify their heating within a relatively short period what determines their consumption during whole year.

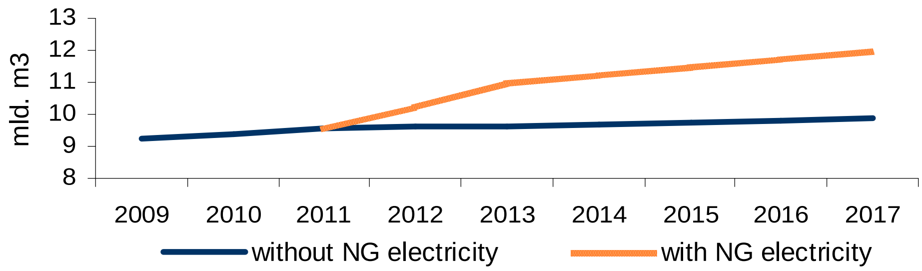
[44] As other customer segments almost do not offtake any gas during warm periods, the share of major customers on total monthly consumption substantially rises with warm weather (due to consumption of gas that is used in production – resistant against high temperatures).

♦ ***Gas demand forecasts***

Companies commonly work in predictions of future consumption with the normal temperature. In prognoses of the Balance Centre[45], national consumption is expected to rise between 0.6% and 4.2% a year until 2013 when considering average daily temperature in particular years to be 8°C. In the long term prediction of MIT (2008), natural gas demand is expected to rise between 0.5 and 1.2 percent a year until 2017 with assumption of long term price stabilization and emphasizing usage of natural gas as an ecological fuel. Although the reality may be in the end, with potentially noticeable impact of weather, pretty different from the plan, one should logically count with some normal temperature when creating expectations.

Among other important factors influencing gas demand belong primarily long term economic development and building new steam and gas power plants. Since natural gas is used in the Czech Republic for electricity generation only insufficiently (according to the Austrian Energy Agency only 4.79% of electricity generation[46] in 2005), this commodity is employed in producing electricity about five times less than in countries of western Europe.

Figure 15: Natural gas consumption forecast until 2017



Source: MIT[47]

It is possible that consumption will rise in the near future primarily due to heightened interest in electricity generation from natural gas (see Figure 15), which could be consequently used in generation of some 20% of national electricity supply by 2017. Beside ČEZ, the main player in the Czech electricity market, also J&T and

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[45] See http://www.upd.cz/upd_soubory/prognoza.html.
[46] See http://www.energyagency.at/enercee/cz/supplybycarrier.en.htm.
[47] MIT (2008): *Natural Gas Consumption Outlook.*

E.ON presented projects[48] on building new natural gas power plants in the Czech Republic.[49] Since the first plant could be started in 2012 at earliest, it is still a question what will be the final output from all these projections. But since this topic is nowadays highly discussed, it is likely that the share of natural gas on electricity generation will noticeably rise, what would in the end bring additional volumetric risk to the Czech natural gas market because weather could potentially influence also new volumes of the commodity demanded by these power plants.[50]

[48] J&T is one of the most active investor groups in the Czech Republic and also Slovakia and is also an important long term investor in the energy industry. E.ON is one of the main players in whole European energy markets, trading both electricity and natural gas.
[49] Even though MIT still counts with gas electricity plants as a marginal electricity source, there have been announced projects with the total capacity about 2,000MW a year what is yearly output of nuclear power plant Temelín. For example, only ČEZ's intention is to build electricity plants in the northern Bohemia with the total capacity of 1,200MW.
[50] Since there is a portion of electricity generated for cooling requirements during summers. If the summer is colder than usually, it is reflected is lower electricity generation for cooling requirements and therefore also in lower natural gas demand. .

3. WEATHER IN THE CZECH GAS MARKET

The natural gas industry, where profits of companies rely heavily on consumed volumes, is one of the most sensitive to weather as the usage of natural gas highly varies with changes in weather, especially in temperature during the heating season. What is more, financial risks associated with fluctuating consumption are further accompanied by the correlation between demand and prices. A sign of periods with high natural gas demand are also high commodity prices, whereas low natural gas loads are affiliated with lower prices. Hence, there is a more pronounced impact on company's financial performance during periods of high consumption.

To protect utilities' revenues against changes in weather are designed weather derivatives. In order to quantify the capability to use them by companies in the Czech natural gas market, we have to undertake an analysis of the relationship between natural gas consumption weather variables. Similar analysis was performed for example by Zanotti et al. (2003) who were looking for the relationship in the Italian natural gas sector. That was done through the investigation of existence of a statistically significant relationship of natural gas consumption and various weather variables. With regard to data for the Czech Republic, we are considering the dependency of consumption on only one weather variable - temperature, which has certainly the heaviest impact on the natural gas market. This study should reveal whether it would be favourable to use weather derivatives in the Czech gas market.

3. 1. Literature review

Many authors have been in different ways investigating the dependency between weather and economic performance. Some of them went through estimating of weather patterns; others used for example Box-Jenkins approach to time series data. For example Roustant et al. (2003) capture the majority of features affecting natural gas demand with several variables included in the model, e.g. temperature, trend, seasonality, volatility or consequently also price uncertainty. Determination of a trend or seasonality might be beneficial for option pricing.

What we do in this thesis, and what was frequently applied in the past, is searching for the relationship of natural gas consumption and temperature with linear regressions. For example Cao and Wei (2001) performed a basic linear regression to show the dependency of monthly natural gas demand on temperature for Illionois residential customers for the period starting with January 1994 and ending by February 1998. Even with this basic statistical method, they reached the explanatory power (expressed by R-Square) of the model equal to 92% that corresponds to an extremely high impact of temperature on natural gas consumption.

Abiodun (2002) demonstrates some 5-6% impact of 1°C change in temperature on natural gas consumption. Considering other weather variables, influence of consumption by snow, rain and wind reaches maximally 5%, respectively 2% and 0.5%. The effect of bank holidays is generally estimated to cause fall in consumption between 5 and 20%.

Also Perchard et al. (2000) assess temperature as the key factor affecting the level of natural gas demand in the United Kingdom. As a rough estimate, a change in temperature by 1°C during winter is reflected in change in demand of 5-6%. An interesting finding is also the fact that the dependency of natural gas demand on temperature is approximately linear for temperatures below 14°C. The impact of weather on consumption starts to weaken over this level and is insignificant for temperatures above 18°C.

Tol (2000) investigates through regression methods the impact of weather volatility on international tourism, agriculture, water, natural gas and energy consumption in Netherlands. He sets a model of annual gas consumption that is applied to three customer segments: domestic, industrial and power plants. Temperature, natural gas price, lagged value of consumption and weather trend are included in the model as explanatory variables. The total R-Square of the regression reached 89.5% with the following results for particular customer segments:

- households – 96%
- industry – 81%
- power plants – 73%

Temperature played a fundamental role in Tol's estimation as degree-days correctly indicate natural gas usage in the market. An interesting finding is also a fall in households' consumption with increasing price of the commodity. As there is no proven link between electricity generation and weather, he alleges that the usage of natural gas for power generation in Netherlands is not related to degree-days.

Several authors were interested also in evaluation of risks linked to weather variability with the aim of consequent assessing of hedging opportunities. Campbell and Diebold (2000) believe that weather forecasting is crucial to all participants in the weather derivatives market. The mere fact that for example utilities or energy companies face weather fluctuations does not mean any significant weather risk if the variability is highly predictable. Weather risk is therefore seen to emerge from the unpredictable component of weather fluctuations – so called "weather noise". To determine hedging potential and formulate respective hedging strategy, it is essential to stipulate how much weather noise exists in the market.

Also Zanotti et al. (2003) search for the existence of statistically significant relationship between daily gas consumption in two Italian cities, Milano and Palermo, and temperature, rain, humidity or air pressure. They estimate an econometric model (with R-Square of 97.5%) to forecast natural gas load as the first step leading to potential hedging of weather risk. They found out that in both cities is temperature the most significant explanatory variable while humidity and air pressure were considered as statistically insignificant. In accordance with their expectations, also high influence of seasonality was present.

3. 2. Summary of raw data

Both deregulation process and current global financial situation further underlined the growing importance of cost and revenue control. Since companies usually build their business plans around some normal temperature, temperature's variability may cause, despite of highly improved accuracy of weather forecasts in recent past, perceptible changes in demand and subsequent significant financial losses.

By reason that we are focused on hedging capabilities of weather risk, let us now introduce the data we are using. With the aim of consistency, we work with daily data for the period of 11 years; from January 1, 1998 to December 31, 2008 that count in total 4,018 observations.

3. 2. 1. Data on temperature

Weather variables are commonly built on a weather index for a particular city. Thus it is reasonable to assume the weather index that considers temperature observations in Prague, as the biggest and best known city in the country, as the most plausible to be selected by companies providing weather insurance. Thus, we work with the data provided by the Czech Hydrometeorological Institute[51] (CHMI) on daily average temperatures at the measure point Prague – Ruzyně[52], which is both well suited and frequently used. We compute the daily average temperature as the mean of daily maximum and minimum, that is a common practice in derivatives' markets (see e.g. Mraoua et al. (2005)).

$$T_{avg} = \frac{T_{\max} + T_{\min}}{2} \quad (1)$$

We use temperature measurements in Prague as a basis for whole country, although there might be observed climate diversities between particular regions. Nevertheless, the situation in the Czech Republic is completely different than in the U.S. or Italy.[53] Regarding both location and area of the Czech Republic, climatic conditions within the country are in general relatively stable and therefore Prague's temperature does not deviate from the republic's average.

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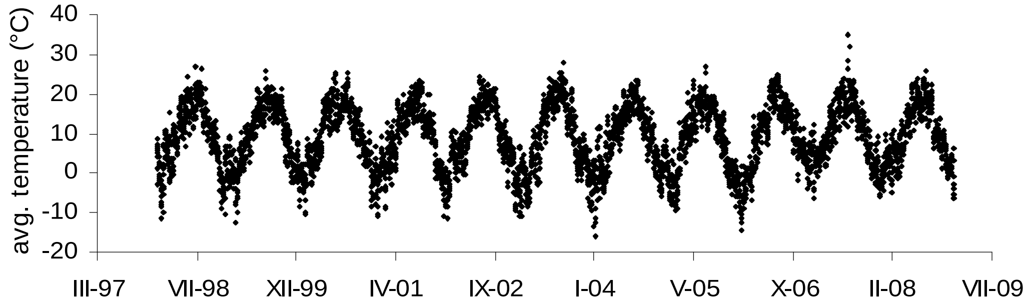
[51] CHMI is the central State institute of the Czech Republic in the field of air quality, hydrology, water quality, climatology and meteorology.

[52] As there was one observation missing on May 5th, 2007, the republic's average temperature was used in this case.

[53] If we were for example in the U.S. where weather is completely diverse in the north than in the south, it would be essential to study weather impacts with regard to these miscellaneous weather conditions.

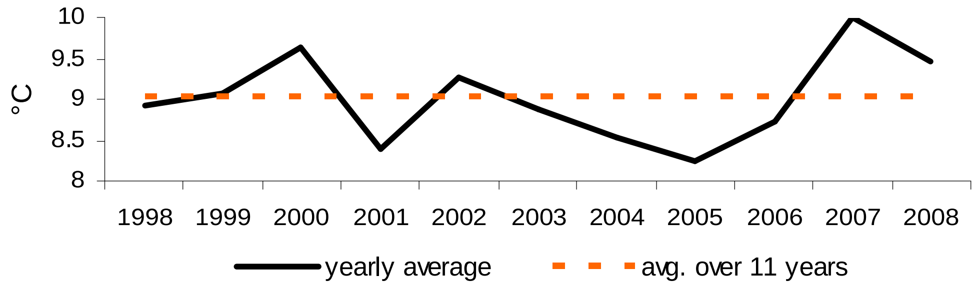
Figure 16: Daily average temperatures at Prague – Ruzyně since 1998



Source: CHMI

Average daily values for the last eleven years plotted in Figure 16 reveal unsurprisingly strong seasonality in temperature, which corresponds with the general feeling that temperature moves repeatedly through periods of high and low levels as periods of the year are changing.

Figure 17: Yearly average temperatures



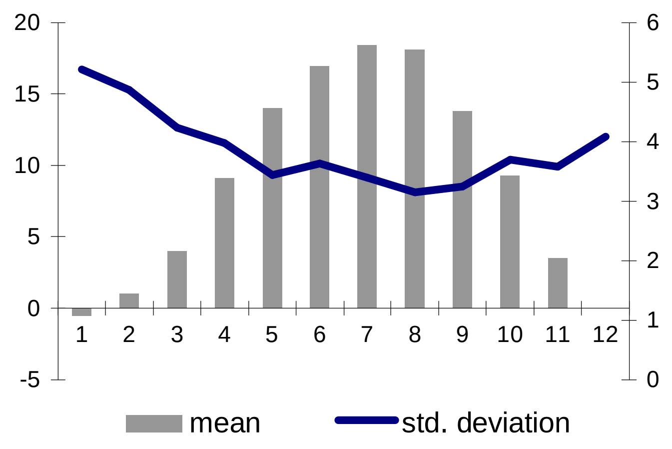
Source: CHMI

Figure 16 and Figure 17 declare that the last three years were relatively warm, especially winters, in comparison with the foregoing. Despite this fact, there does not seem to be any significant trend of increasing average temperatures in the long term.

Apart from the yearly average temperature, more important for natural gas companies seems to be identifying of temperature variability over particular months. Since there is a significant impact of variations in temperature on natural gas consumption, it is important to identify, also for the purpose of potential hedging, when the variations in temperature reach their peak during the year.

With regard to Figure 18 it is facile to determine warm and cold periods (months) during the year and that temperature highly varies during periods when its monthly averages are low. Since the average daily temperature over the last eleven years was 9.0122 °C, the period from April to September could be labelled as warm, i.e. containing months with average temperatures above the yearly average, while the period from November to the end of March might be considered as cold.

Figure 18: Daily temperatures per months – mean and standard deviation (°C)



°C	mean	std. deviation
January	-0.5566	5.2170
February	1.0289	4.8661
March	4.0088	4.2305
April	9.0735	3.9812
May	14.0436	3.4356
June	16.9522	3.6364
July	18.4141	3.3993
August	18.1189	3.1448
September	13.8205	3.2409
October	9.2889	3.6929
November	3.4889	3.5771
December	-0.0026	4.0856

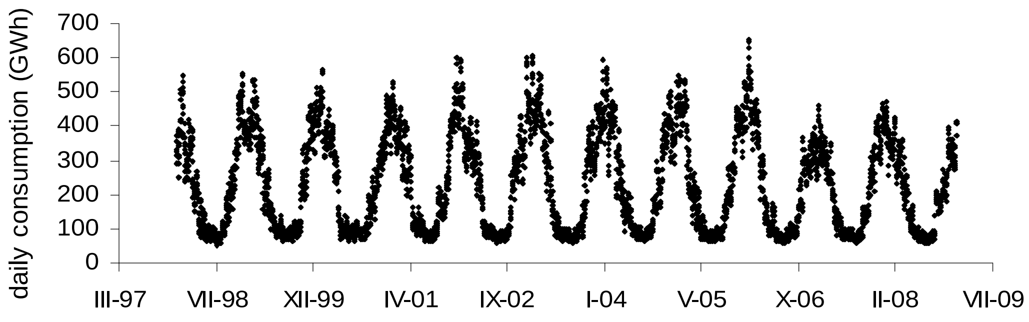
Source: CHMI

3. 2. 2. Data on consumption

We work with daily data on natural gas consumption provided by the Balance Centre and the main player in the Czech natural gas market - RWE TG. We use large and consistent share of consumption, which may approximately represent even the whole Czech natural gas market.

The behaviour of natural gas consumption over the last 11 years is outstandingly cyclic (as shown in Figure 19). Consumption reaches peaks in winters when temperature is the lowest, while it falls to the bottom during summers that are characterized by high temperatures. Also in view of the impact of warm winters of 2006, 2007 and 2008 on average natural gas consumption, the presence of a significantly negative correlation between temperature and consumption is evident.

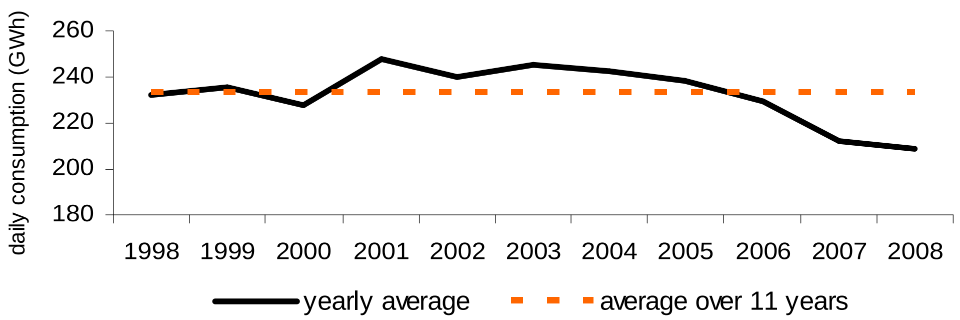
Figure 19: Daily gas consumption since 1998



Source: BC & RWE TG

The trend of decreasing average daily natural gas consumption in recent years that is significant in Figure 20 corresponds also to high daily average temperatures in this period (shown in Figure 17).

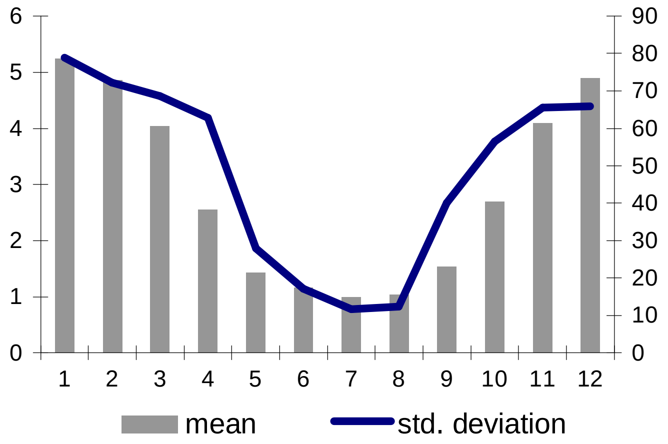
Figure 20: Average daily natural gas consumption (GWh)



Source: BC & RWE TG

In a similar way as it is done for temperature, we search for monthly patterns in natural gas consumption and for periods when its volatility is high. As both mean and standard deviation of daily consumption are the lowest from May to September, it may serve as an indicator that hedging against weather risk is not necessary for these months. In addition, also standard deviations of temperature are of low-levels during this period.

Figure 21: Monthly consumption – mean (multiple of July) and std. dev. (GWh)



	mean (*July)	std. dev. (GWh)
January	5.245	78.961
February	4.858	72.317
March	4.042	68.620
April	2.564	62.818
May	1.428	27.863
June	1.170	17.076
July	**1.000**	**11.620**
August	1.034	12.426
September	1.541	39.981
October	2.687	56.386
November	4.093	65.461
December	4.897	65.959

Source: RWE TG and BC[54]

3. 2. 3. Empirical idea

Also with regard to the figures on cyclical development of consumption and temperature, a strong negative correlation between these two variables is evident in the Czech market. To make clear the background behind the notion of correlation, it is possible to look at cyclical behaviour of temperature and natural gas consumption also with the aid of histograms.

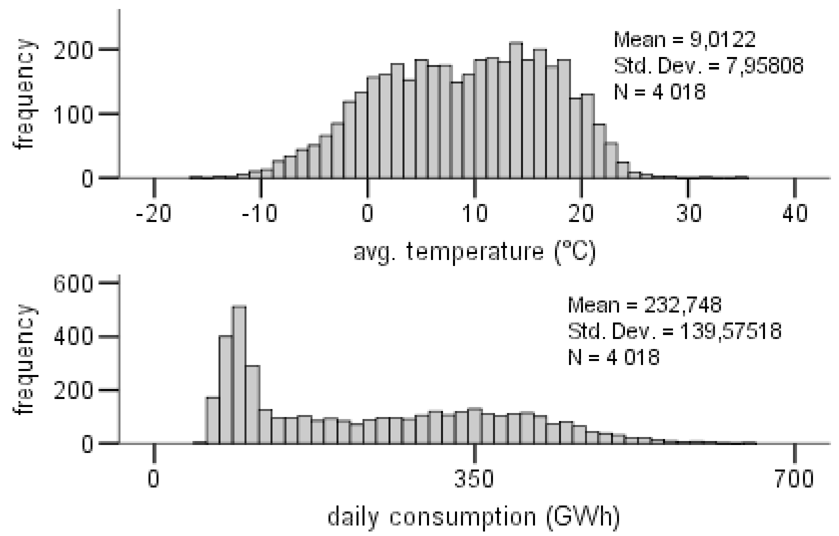
Figure 22 shows that the distribution of temperature is slightly bi-modal; with peaks in winter and summer that is quite usual for the majority of temperature distributions of countries with similar weather conditions to the Czech republic. Temperature measurements at Praha – Ruzyně station, with the mean of about 9°C, seem to approximately follow the normal distribution. The majority of observations are situated somewhere between 0 and 20 °C.

With relatively few measurements above twenty degrees, the distribution becomes more skewed with increasing values which correspond to just a small number of tropical days in the Czech Republic. On the other hand, lower number of

[54] Ii order to do not give exact numbers on averages, I have chosen July's value to be equal 1 (as it has the lowest mean among all months) and means of other particular months are consequently presented as multiples of July's mean.

instances with temperatures below zero reflects characteristics of mild winters, which are usually relatively long but without any extreme temperature measurements.

Figure 22: Histograms of daily temperature and gas consumption (1998 – 2008)



Source: CHMI, BC & RWE TG

The histogram of daily consumption indicates different behaviour than of temperature as the distribution is relatively stable. Since the highest frequency appears for low consumptions, it intuitively corresponds to the fact that consumption becomes stable (driven mainly by the base-load demand) with high temperatures.

3. 3. OLS regression methods

Understanding and adequate control of volatility in earnings should be an objective of all natural gas companies. In order to analyze hedging capabilities in the Czech natural gas market and consequently find a valuable hedging strategy against volume risk, an investigation of the dependency of consumption on weather (temperature) with assigned statistical analysis should be primary steps.

What is more, an accurate econometric model can serve as the first instance in protecting against threats of adverse weather (temperature). It is a common practice in the gas business that traders add into customers' contracts paragraphs regarding yearly, monthly or daily flexibility in off-takes. Especially in this highly weather dependent business, an accurate regression model may serve as a benchmark for setting up flexibility bands in contracts (instead of using a plain percentage of volumes).

Larsen (2006) claims that the substitution of observed weather measures into a robustly estimated regression equation should produce observable distributions in the output of a given sector. According to Gil et al. (2004) the most important factors affecting natural gas consumption of residential and commercial users are:

- temperature
- day of the week, i.e. effect of working days and holidays
- prevailing scenario of consumption

Results of such an analysis could be further improved by the addition of price into estimated models as there is generally present significant impact of price on natural gas consumption. For example Tol (2000) has proven that higher commodity prices lead to reduced natural gas consumption, especially by households.

3. 3. 1. Linear dependency

It is obvious that temperature highly determines total consumed volumes of natural gas. The question in the Czech market is: *"How much?"* In order to analyze this relationship, we start with a basic linear regression and application of the ordinary least squares (OLS) method.[55] Hereafter, we try to fit the model correctly to real-life observations also by adding other variables than just temperature on a given day.

Since daily gas consumption (G) is the dependent variable whereas temperature (T) is explanatory, the linear regression's equation looks as follows:

(2) $$G_t = c + a \cdot T_t + e_t$$

If we had information on natural gas prices, a similar analysis could be performed for companies' revenues instead of consumed volumes.

Regression results on the 5% level of significance are obtained with the help of SPSS econometric software. With regard to the results, it is obvious that fluctuations in natural gas consumption can be greatly explained by variability in temperature as R-Square reaches 88.8%. What is more, all regression coefficients are significant with only low standard errors. Also the correlation coefficient between the explanatory and

[55] For more information to this method see Appendix.

dependent variables of -94.3% indicates a strong negative linear relationship between consumption and temperature (see Figure 23). According to the results of this regression, daily natural gas consumption would rise by approximately 16.5 GWh with a fall in temperature of 1°C.

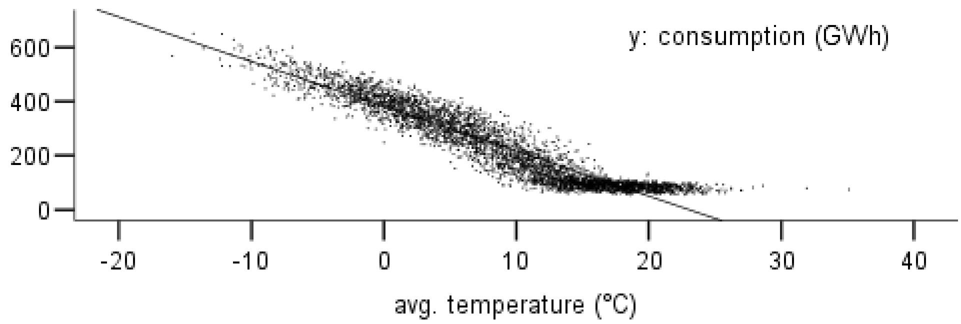
Table 2: Simple linear regression results

variable	coefficient	std. error	t-statistic	signif.
const.	381.724	1.112	343.31	0.000
T_t	-16.531	0.092	-178.735	0.000
R-Square	0.888			
adj. R-Square	0.888			
std. error	46.648			
Durbin-Watson	0.610			

Source: Author

As shown in Figure 23, the approximately linear relationship between consumption and temperature is abandoned when temperature rises above some threshold level that lies between 10°C and 20°C. At this point, consumption starts to be highly inelastic in temperature, which is similar behaviour as demonstrated by Perchard et al. (2000) for the United Kingdom.

Figure 23: Linear regression – consumption dependency on temperature



Source: Author

Considering the results of linear regression, consumption would reach zero with the temperature of approximately 23.1°C.[56] However, there always exists some base-load consumption especially because of the industries that use natural gas in the

[56] And would be negative with even higher temperatures what is in contrast with the basic presumption that consumption is non-negative.

process of manufacture (e.g. glass producers) even during warm days and also the residential demand for the commodity further used in cooking

3. 3. 2. Weekend factor

As another highly important factor that determines natural gas demand is perceived the presence of weekends and holidays. Consumption is in general lower at weekends by reason that industrial loads are commonly higher during weekdays. Therefore we add into the model also the “weekend factor” that covers the presence of both public holidays and weekends.

(3) $$G_t = c + a \cdot T_t + b \cdot WEEKEND_t + e_t$$

Although weekend’s consumption is inherently included in time-series models, it has to be manually implemented into regression models. Since dummy variables are numerical variables used in regression analyses to represent subgroups of a sample, application of dummies seems to be the most suitable way to model the “weekend factor”. Since the purpose is to distinguish weekend patterns in consumption, the variable called ‘*WEEKEND’* has the value of 1 if a particular day is a weekend day or public holiday and equals 0 otherwise.

Table 3: Linear regression with weekends

variable	coefficient	std. error	t-statistic	signif.
const.	390.977	1.168	334.707	0.000
T_t	-16.573	0.089	-187.167	0.000
weekends	-29.525	1.537	-19.211	0.000
R-Square	0.898			
adj. R-Square	0.898			
std. error	44.647			
Durbin-Watson	0.584			

Source: Author

The results of an improved model correspond to our presumption since the presence of weekends and holidays leads to the fall in consumption by 29.525 GWh. Explanatory power (R-Square) has increased to 89.8% by adding the weekend factor. If there was no such a factor in the regression, results would lead to regular underestimating of consumption on weekdays while overestimating at weekends.

3. 3. 3. Setting a threshold on temperature

Hereafter, we make the first attempt to catch the non-linearity in the relationship of natural gas consumption and temperature. Beside other regression types[57], there exist a way of dealing with nonlinearity when performing linear regressions. Because consumption tends to become stable with high temperatures, there might be set a cap on temperature to catch with the regression only weather dependent consumptions.

(4) $$T_t = \min\left(T_{real}; T_{threshold}\right)$$

This would correspond to the fact that consumption stays close to a constant level with temperatures above some threshold level of temperature and that there is almost no additional decrease in consumption with further increasing temperatures.[58] An empirical explanation is that the threshold level represents the daily temperature associated with minimum heating natural gas demand.

Similar transformation is commonly done in derivatives' markets with application of so called degree days as we will show later in more detail (Chapter 4.1.1.). We analyze impacts of employing of various temperature levels as heating thresholds because determination of the most appropriate threshold level may greatly help also in looking for the most efficient hedging strategy.

It would be logical to proceed analogically also for very low temperatures. Since consumption increases due to growing heating demand when temperature goes down, it is obvious that the level of temperature where consumption becomes inelastic in temperature should exist. The reasoning is straightforward as heating capacities meet at some point their maximum level and thus it is even technically impossible to further increase consumption. However, such a level does not seem to be reached in

---

[57] See later in the thesis (Chapter 3.3.4.).

[58] Another manner to set a threshold for temperature could be transformation into the degree day format, what has been chosen many times before, e.g. Zanotti et al. (2003), de Dear et al. (2003) etc. This is not just a way how to deal with non-linearity in dependency, but it is also a change to the manner that insurance companies commonly use when provide hedging as I will show later. However, I use just plain cap on temperature measurements for the purpose of data analysis (as it is more appropriate for example for non-linear regression techniques).

the Czech Republic in the past (as it is also obvious from Figure 23) because average temperatures are relatively high even during the coldest days.

As Figure 23 implies that the point where consumption starts to be approximately constant lies somewhere between 10°C and 20°C, we perform regressions with included weekend factor (see equation (3)) for particular thresholds (that vary from 13°C to 18°C).

(5) $$G_t = c + a \cdot \min(T_{real}; T_{treshold}) + b \cdot WEEKEND_t + e_t$$

Table 4: Comparison of regressions with capped temperature

results	cap 13	cap 14	cap 15	cap 16	cap 17	cap 18
R-Square	0.912	0.923	0.929	***0.930***	0.929	0.924
adj. R-Square	0.912	0.923	0.929	***0.930***	0.929	0.924
std. error	41.356	38.695	37.213	***36.836***	37.320	38.390
Durbin-Watson	0.629	0.695	0.732	***0.735***	0.710	0.674

Source: Author

By performing these particular regressions, we have manually done something similar what generally do also robust statistical methods [59] that deal with influential observations (outliers). Nevertheless, there are three reasons why to use a cap since:

- robust methods would limit us in further transformations of the model
- the manual method better demonstrates differences between various caps
- for the purpose of consequent hedging, we need to use integers what would not be the case of robust methods, which would simply choose the most appropriate value

(6) $$T_t = \min(T_{real}; 16°C)$$

Table 5: Linear regression with temperature capped at 16°C

variable	coefficient	std. error	t-statistic	signif.
const.	400.639	0.985	406.850	0.000
T_t (cap at 16°C)	-19.192	0.083	-230.971	0.000
weekends	-29.846	1.268	-23.537	0.000

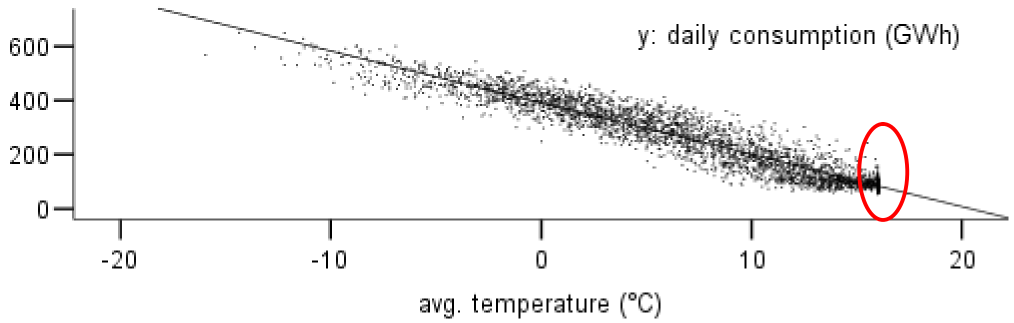
Source: Author

[59] For example Least Trimmed Squares.

The highest explanatory power of the model is reached with the cap set at 16°C. The regression curve with capped temperature better fits reality during months with highly weather dependent consumption as R-Square in these models highly accrues, in the best case even to 93% (compared with 89.8% when considering uncapped data). When comparing regression results with (Table 5) and without a cap (Table 3), there are higher constant term and impact of a change in temperature in the capped case.

By capping temperature at 16°C, the regression line (basic regression without the weekend factor) becomes steeper than in the uncapped case as there is not considered any additional impact of temperatures higher than the threshold. Thus, there is a bunch of observations with the temperature of exactly 16°C as measurements with higher temperature have been moved to the left to equal 16°C as well.

Figure 24: Simple linear regression with a cap (16°C)



Source: Author

The regression model with implemented cap better explains the area where consumption is highly dependent on temperature. The model is not biased by temperature observations above 16°C because there is almost no effect of weather on consumption on days with temperature higher than 16°C. Since Pearson correlation of daily consumption and actual temperature was -94.3% without any cap, it has amplified to -96% with temperature measurements capped at 16°C.

Considering the results shown in Table 4 and Table 5, we have already proven that the weekend factor and cap on temperatures are greatly useful to improve the explanatory power of the model.

3. 3. 4. Other regression types

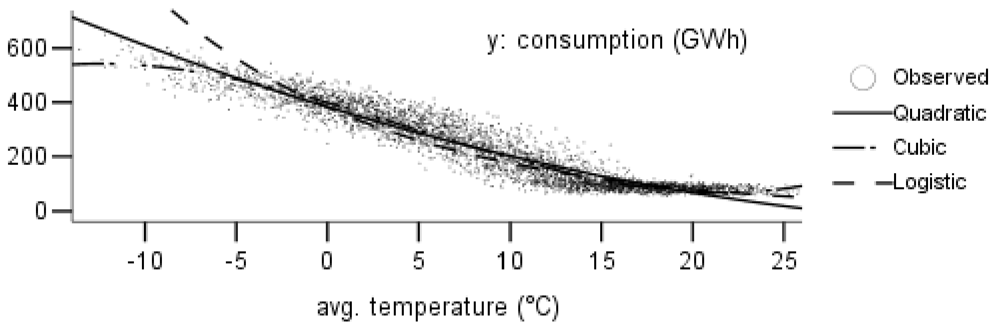
In order to capture the nonlinearity in the dependency differently than with capped temperatures, regressions with specific appearance of a curve should be applicable with satisfactory results as well. Despite the results of linear regression, the relationship between temperature and consumption seems to follow a curved line instead of straight. With regard to the nature of other regressions, quadratic (7), cubic (8) or logistic (9) regression could be in general more suitable for modelling the dependency.

(7) $$G_t = c + a \cdot T_t + b \cdot T_t^2 + e_t$$

(8) $$G_t = c + a \cdot T_t + b \cdot T_t^2 + g \cdot T_t^3 + e_t$$

(9) $$G_t = \frac{1}{1 + e^{-(c + a \cdot T_t)}} + e_t$$

Figure 25: Other regression types



Source: Author

In view of regression curves shown in Figure 25 and results in Table 6, the cubic regression seems to be the most appropriate among considered alternative methods. The S-shaped cubic regression's curve resembles the straight line with inelastic consumption when temperature crosses thresholds on both sides of its scale.[60]

If we take into account only the effect of actual day's temperature, the application of cubic regression might be considered as better even in comparison with

[60] If natural gas was highly used for electricity generation, the application cubic S-curve would be even more appropriate. From some level of temperature, consumption would be likely to increase again with rising temperatures due to high air-conditioning demand for electricity.

the linear form as it has the highest explanatory power (see Table 6). If cubic regression is further improved with the weekend factor, slightly better results (shown in Table 7) are obtained.

Table 6: Linear vs. nonlinear regression methods

regression	R-square	c	α (T)	β (T^2)	γ (T^3)
linear	0,888	381,724	-16,531		
quadratic	0,902	382,815	-20,397	,234	
cubic	0,920	398,928	-19,401	-,332	,024
logistic	0,873	,003	1,080		

Source: Author

As it is obvious from Table 7, the cubic regression, as the best one among other regression types, leads to better results than the basic linear regression (see Table 3). Nevertheless, capturing of the nonlinearity by implementation of the threshold level on temperature into the basic linear regression model highly improves the explanatory of the model which consequently reaches 93%, that is higher than R-Square of the cubic regression. Therefore it is not much favourable to use the cubic regression as it is possible to capture the nonlinearity of the model better with a quality linear regression model (e.g. given by equation (11) as we will see later).

Table 7: Cubic regression

variable	coefficient	std. error	t-statistic	signif.
const.	408.239	1.098	371.814	0.000
T_t	-19.457	0.160	-121.800	0.000
T_t^2	-0.331	0.020	-16.791	0.000
T_t^3	0.024	0.001	31.642	0.000
weekends	-29.684	1.279	-23.217	0.000
R-Square	0.929			
adj. R-Square	0.929			
std. error	37.141			
Durbin-Watson	0.727			

Source: Author

3. 3. 5. Implementing lagged temperatures

Even though the model with high explanatory power has been already reached, there remain other features that should be logically included. Zanotti et al. (2003)

relate a relatively low R-Square in their model to the presence of lagged effect of weather variables, i.e. the influence of past observations on temperature.

Even unsophisticated logic lies in the background of this argumentation as the impact of past temperature on present consumption can be partially explained for example by thermal insulation of buildings. When temperature is very cold on two subsequent days, households adjust their consumption since houses generally do not need to be heated with the same intensity on the second day to reach desired effect. Similar justification holds for industrial customers as they adjust heating only if similar weather conditions take at least for several days.[61] Thus, consumption on two particular days with the same temperature, but in different periods of the year, is generally higher in winter.

Therefore we further consider several intuitive scenarios of impacts of past temperature measurements on consumption, including both short and long term effects.

♦ ***Impact of prior days' temperatures***

It is very likely that apart from actual temperature on a given day, consumption is affected by temperatures on directly preceding days. Hereafter, we are intuitively concerned with impacts of daily lags up to five prior days to capture short-term impact of temperature. Running the stepwise regression[62] in SPSS, the best possible estimators are obtained when considering the constant term, actual and lagged temperatures (all capped at 16°C) and weekend factor in the regression (as shown in equation (10)).

(10)

$$G_t = c + a \cdot T_t + b_1 \cdot T_{t-1} + \cdot b_2 \cdot T_{t-2} + b_3 \cdot T_{t-3} + b_4 \cdot T_{t-4} + b_5 \cdot T_{t-5} + g \cdot WEEKEND_t + e_t$$

Considering results of the stepwise regression, the model has high explanatory power with all the coefficients in equation (10) being statistically significant. But since subsequent daily temperatures are likely to be correlated among each other, one

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[61] Gil and Defarri (2004) apply this logic in their concept of effective temperature when modeling natural gas demand.

[62] What means that the software automatically selects significant variables and performs several particular regressions whose results are consequently aligned according to their R-Squares.

needs to be aware of a potential problem with multicollinearity of explanatory variables.[63] With all lagged values included in the regression, the Variance Inflation Factor[64] (VIF) indicates this problem.

Table 8: Regressions with lagged temperature

results	coeff.	std. error	VIF	coeff.	std. error	VIF
	with all lags			with omitted lags		
const.	409.870	0.730		409.535	0.757	
weekends	-29.725	0.918	1.002	-29.528	0.952	
T_t	-10.526	0.205	11.618	-12.899	0.131	4.385
T_{t-1}	-2.558	0.288	22.959			
T_{t-2}	-2.035	0.291	23.327			
T_{t-3}	-1.574	0.291	23.297	-4.121	0.172	7.629
T_{t-4}	-0.677	0.288	22.907			
T_{t-5}	-2.934	0.205	11.587	-3.250	0.151	5.822
R-Square	0.964			0.961		
adj. R-Square	0.963			0.961		
std. error	26.669			27.658		

Source: Author

As it has not heavy impact on explanatory power of the model, the stepwise regression method suggested exclusion of the first, second, and fourth lag in order to press all VIF values below 10 and thus lessen the multicollinearity issue. As a result, standard errors of particular coefficients have decreased while values of three kept estimated coefficients on temperature have increased (see Table 8).

Based on the results shown in Table 8, the model with omitted temperature lags reaches R-Square of 96.1%. Regarding the impact on actual day's consumption, actual temperature higher by 1°C lowers consumption by approximately 12.9 GWh. Increase in temperature by 1°C three, respectively five days ago brings three and four times lower effect than of the actual day.

♦ ***Long term lags***

As we have already mentioned, for two days with the same temperature where one is in winter and the other in summer, there is higher consumption on a winter day.

[63] Multicollinearity means that two or more explanatory variables may be explaining the dependent variable well but at the same time are closely mutually correlated.

[64] VIF measures the impact of collinearity among the variables in a regression model. Even though there is no formal value of VIF that determines presence of multicollinearity, VIF exceeding 10 is generally perceived as a multicollinearity indicator.

It corresponds to the fact that natural gas consumers generally do not adjust their heating devices unless weather remains alike at least for several days or even weeks. Consequently, we try to capture even the long term impact of temperature on consumption.

Since there was detected the problem with multicollinearity when using temperatures lagged up to five days, transformation of daily data over more days into one variable could be a solution. Therefore, we try to implement the average of temperatures from the first to the sixth lagged day into the model what should capture the influence of directly preceding days (week). Furthermore, by implementation of another average we test also the significance of daily temperatures lagged from seven to 30 days, which should reflect actual period of the year and thus heating requirements in longer term (month).

(11) $$G_t = c + a \cdot T_t + b \cdot T_{(t-1;t-6)} + g \cdot T_{(t-7;t-30)} + d \cdot WEEKEND_t + e_t$$

Table 9: Linear regression with weekly and monthly lags

variable	coefficient	std. error	t-statistic	VIF
const.	413.492	0.722	572.393	
weekends	-29.606	0.879	-33.669	1.001
T_t	-10.961	0.139	-78.762	5.838
$T_{(t-1 - t-6)}$	-7.575	0.175	-43.312	8.453
$T_{(t-7 - t-30)}$	-2.209	0.132	-16.781	4.312
R-Square	0.967			
adj. R-Square	0.967			
std. error	25.543			
Durbin-Watson	0.473			

Source: Author

The model with such a clear and understandable selection of temperature observations shows descending impact of changes in temperature when going back to the past. Nevertheless, even the average of daily temperatures lagged up to 30 days is still significant in the regression with regard to its t-statistics and p-value (0.000). Furthermore, the explanatory power of the model with long term lags rises to 96.6% and there is not indicated any problem with multicollinearity. Therefore it is obvious that it is convenient to consider also the long term effect of weather on natural gas consumption, which is not a prevailing practice in similar studies.

3. 4. Interpretation of results

It would not be an exception if the results from the previous chapter were sufficient for a natural gas trader and therefore applied in predictions of consumption. But beside just an economic point of view, one has to take into account also the statistical approach to interpret the results well.

Since we have quality data, there are no problems with outliers[65] or omitted variables and we have already dealt with multicollinearity issue in Chapter 3.3. Above all, it is necessary to check potential troubles with residuals as for example Durbin-Watson statistics (for more information see Appendix) indicated autocorrelated residuals in the model. To interpret the results of our model (given by equation (11)) well, it is important that OLS assumptions about residuals are fulfilled (for more information about OLS see Appendix).

3. 4. 1. Analysis of residuals

Herein, we investigate the presence of three most common problems with residuals in regression models that could in the end cause troubles in the interpretation of results.

- ***Normality***

With regard to the descriptive statistics shown in Table 10, it is obvious that residuals with a zero mean and values of skewness and kurtosis higher than -1, respectively lower than 1, fulfil the presumption of normality. Since residuals are normally distributed, estimated coefficients with OLS are not biased. Nevertheless, it does not mean that the estimator is efficient.

Table 10: Regression residuals

	sum	mean	skewness	kurtosis
residuals	0.000	0.000	-0.157	0.393

Source: Author

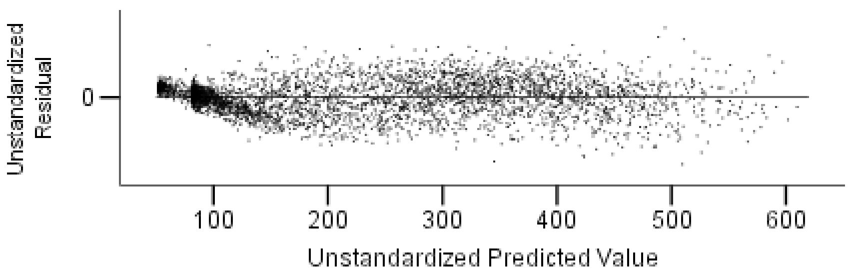
[65] Since there are just 16 observations with standardized residual's values higher than 3 what is often perceived as a sign of outlier.

♦ ***Heteroskedasticity***

Since we apply OLS method to time series data, there might generally appear two problems with residuals: heteroskedasticity and autocorrelation. If there is present any of these problems, standard errors of estimated coefficients are biased and thus the model is not efficient.

A notion on heteroskedasticity can be easily obtained even by plotting regression residuals into the same graph with e.g. predicted values of a dependent variable as it is done also in Figure 26. Since there is higher variance of residuals with increasing values of consumption, the presence of heteroskedastic residuals is indicated. It corresponds with the basic structure of daily consumption that highly varies especially in winters due to adjustments of heating devices. On the other hand, as the share of base-load consumption increases during warmer days, the variability of consumption greatly falls.

Figure 26: Residuals' variance



Source: Author

Consequently, standard White test for heteroskedasticity[66] of residuals is performed with the help of EViews[67] statistical software. Based on its results, the hypothesis on homoscedastic (homogenous) variance is rejected as F-statistic's value of 34.17 without any doubts crosses the critical value and thus the p-value is very low.

With present heteroskedasticity, the OLS estimate stays unbiased and consistent, but not asymptotically efficient. With regard to the nature of

[66] Constant variance of residuals is tested by regressing square residuals from the model onto regressors, cross-products of regressors and squared regressors.
[67] EViews software can be used for general statistical and econometric analyses as time series, cross-section or panel data.

heteroskedasticity in this model[68], it is difficult to eliminate the problem with any transformation of data (e.g. using of natural logarithms). Thus, true variances are underestimated and t-statistics overestimated when using OLS in the model. As a result it would be even possible that we include into the model a non-significant variable due to biased standard errors.

Table 11: White test for heteroskedasticity

results	value	p-value
F-statistic	34.1727	0.0000
Obs*R-Square	401.2761	0.0000

Source: Author

Since a quality model for predicting daily natural gas consumption has been reached and OLS coefficients are unbiased, OLS results would be frequently employed, especially if one considers so large data samples as we have. The only accessory would be the application of White standard errors (see equation (12)) that reflect heteroskedasticity of residuals.

$$White\_SE(\hat{b}_j) = \sqrt{\frac{\sum_{i=1}^{n} \hat{r}_{ij}^2 \hat{u}_i^2}{SSR_j^2}} \qquad (12)$$

where $\hat{r}_{ij}^2$ is the -ith residual from regressing independent variable x_j on all other independent variables and SSRj is the sum of squared residuals from this regression. Consequently, t-statistics are calculated using new standard errors.

White standard errors are commonly used by economists to fix heteroskedasticity problem even though the fix comes with a loss in efficiency. Thus, OLS is not the best linear unbiased estimator[69] (BLUE) anymore. Robust White estimators lead to higher standard errors and lower t-statistics of particular coefficients than application of common OLS statistics. Despite the fact that White standard errors are higher in comparison with OLS errors, there is no impact on the significance of

[68] It is obvious that consumption has higher variance during winters while it generally stays close to some constant value in summers.

[69] BLUE minimizes the variance of a chosen linear combination of the data subject to the constraint that the estimator must be unbiased.

variables in our model since all p-values stay very low even with application of robust standard errors (see Table 12).

Table 12: White robust estimator

variable	coeff.	std. error	t-stat.	std. error	t-stat.	p-value
		OLS std. errors		***White std. errors***		
const.	413.492	0.722	572.393	0.838	493.481	0.000
weekends	-29.606	0.879	-33.669	0.862	-34.362	0.000
T_t	-10.961	0.139	-78.762	0.167	-65.745	0.000
$T_{(t-1 - t-6)}$	-7.575	0.175	-43.312	0.208	-36.483	0.000
$T_{(t-7 - t-30)}$	-2.209	0.132	-16.781	0.150	-14.768	0.000

Source: Author

Since any transformation of data in this case would not help us to avoid heteroskedasticity, robust standard errors are the most appropriate way of dealing with this unwished feature. As the purpose is to estimate daily natural gas consumption, the model is highly explanatoery with usage of OLS despite not being the most efficient. However, a loss in efficiency might be bearable in practical usage of natural gas companies since we obtain greatly understandable results with OLS.

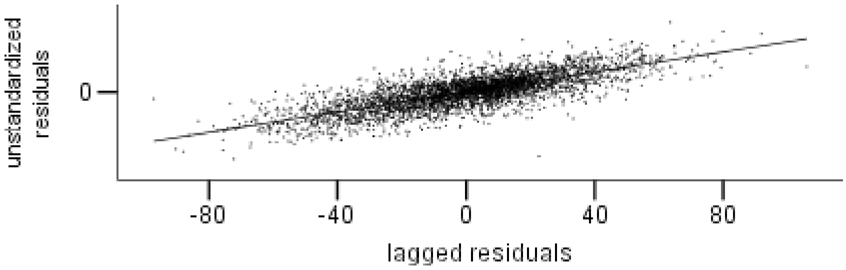
♦ ***Autocorrelation of residuals***

When working with data of time series origin, positive autocorrelation of residuals is not extraordinary since errors from one period of time are commonly carried over into future time periods. If it is weather (temperature) itself or natural gas consumption, which is highly dependent on temperature, trends in these variables generally tend to persist for some time. In all models that we have introduced, the Durbin-Watson statistics indicated serial correlation among residuals, which causes that estimated coefficients are, despite of still being unbiased, inefficient due to underestimated standard errors. As a consequence, also R-Square of the model is overestimated.

As an indicator of serial correlation among residuals is commonly used a plot showing the relationship of residuals and their lagged values. In

Figure 27, by which is shown the dependency of regression residuals on their lagged values of the first order, is revealed strong autocorrelation of residuals in the model.

Figure 27: Autocorrelation of residuals



Source: Author

Since we have already demonstrated that the model suffers from both heteroskedasticity and autocorrelation of residuals, conventional OLS standard errors are wrong and accordingly robust standard errors have to be applied to interpret OLS results well. Since White robust standard errors assume that residuals of the estimated equation are serially uncorrelated, Newey and West (1987) proposed a more general covariance estimator that is consistent with the presence of both heteroskedasticity and autocorrelation of unknown form. The Newey-West method is generally known as application of Heteroskedasticity and Autocorrelation Consistent (HAC) standard errors (see covariance matrix given by equation (13)).

(13) $$\hat{\Sigma}_{Newey-West} = \frac{T}{T-k}(X'X)^{-1}\hat{\Omega}(X'X)^{-1}$$

where

(14) $$\hat{\Omega} = \frac{T}{T-k}\left\{\sum_{t=1}^{T} e_t^2 x_t x_t' + \sum_{v=1}^{q}\left(\left(1-\frac{v}{q+1}\right)\sum_{t=V+1}^{T}\left(x_t e_t e_{t-v} x_{t-v}' + x_{t-v} e_{t-v} e_t x_t'\right)\right)\right\}$$

where T is the number of observations, k is the number of regressors, x_t *is the explanatory variable,* ε_t *is the least squares residual and q (the truncation lag) is a parameter representing the number of autocorrelations used in evaluating dynamics of the OLS residuals* ε_t*.*

As shown in Table 13, HAC standard errors are about two times higher than original OLS errors and consequently also t-statistics change. Nevertheless, calculation of HAC robust estimators reveals that all the coefficients in the model stay statistically significant as their p-values are still very low.

Table 13: HAC estimators

variable	coeff.	std. error	t-stat.	std. error	t-stat.	p-value
		OLS std. errors		*HAC std. errors*		
const.	413.492	0.722	572.393	1.930	214.262	0.000
weekends	-29.606	0.879	-33.669	0.816	-36.276	0.000
T_t	-10.961	0.139	-78.762	0.248	-44.254	0.000
$T_{(t-1 - t-6)}$	-7.575	0.175	-43.312	0.357	-21.246	0.000
$T_{(t-7 - t-30)}$	-2.209	0.132	-16.781	0.355	-6.224	0.000

Source: Author

Despite the fact that a quality model has been reached with OLS method, we have calculated robust standard errors to deal with both heteroskedasticity and autocorrelation. With application of HAC standard errors and t-statistics, one could interpret the estimated model in which all variables stay significant. Nevertheless, since the structure of residuals implies that OLS estimator is no longer efficient, it could be also rewarding to find an efficient model.

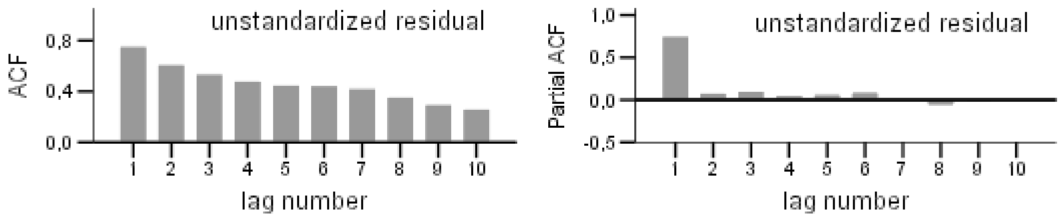
3. 4. 2. Generalized Least Squares

In order to find an efficient estimator of the model, traditional OLS method is no longer satisfactory. Although OLS coefficients are not biased, standard errors and t-statistics tend to be underestimated with present autocorrelation. Thereby for example the Generalized Least Squares (GLS) method should be applied for such models. But prior to application of GLS, one should look at the structure of autocorrelation in more detail.

♦ ***Autocorrelation function***

Hereafter, we search for the form of autocorrelation with usage of autocorrelation functions. Autocorrelation function (ACF) is a very helpful diagnostic tool in time series data analysis as it is estimated by calculation of the correlation coefficient between present and lagged values of a variable. Partial autocorrelation function (PACF) is even more appropriate in the determination of trends and periodicities in the model.[70] Box and Jenkins (1976) recommended usage of PACF as an indicator of the order of an process with a practical rule suggested: if PACF has spikes significantly different from zero at p lowest lags and with higher lags PACF abruptly drops off, an autoregressive process of order p should be selected. In view of Figure 28, the model of natural gas consumption seems to be mainly influenced by the autoregressive process of the first order (where the correlation coefficient equals to 0.761).

Figure 28: Correlation of residuals



Source: Author

Hereafter, GLS method is applied to the model. To be more precise, we use one of GLS variations - the Cochrane-Orcutt (CORC) iterative estimation method. This method, which presumes the first order of autocorrelation structure - AR(1), is performed in several steps.

- ***Cochrane-Orcutt transformation***

The OLS estimate of the model (given by equation (11)) serves as a starting point in this method. Obtained OLS residuals $\hat{e}$ (from equation (15)) are used to get an estimate of coefficient ρ from the regression given by equation (16).[71]

(15) $$Y_t = b_0 + b_1 X_{t1} + ... + b_k X_{tk} + e_t$$

(16) $$e_t = r \cdot e_{t-1} + v_t \quad \textit{for } t = 2, \ldots, N$$

The estimator of ρ is subsequently employed in the construction of transformed observations. Hereafter, OLS method is applied to the transformed model (in general form given by equation (18)).[72]

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[70] Although ACF spike at lag 10 might be statistically significant, it does not necessarily mean that there is a direct effect of lag 10 on the present value of a variable. It is more likely that observation X_{t-10} affects X_t indirectly through the intermediate X values.

[71] To introduce the method, we denote equations for GLS in their general form. However, one could easily install our variables into these general equations.

(17) $$Y_t = X_t B + e_t = X_t B + r \cdot e_{t-1} + v_t = X_t B + r \cdot (Y_{t-1} - X_{t-1} B) + v_t$$

and thus:

(18) $$Y_t - r \cdot Y_{t-1} = (X_t - r \cdot X_{t-1}) B + v_t$$

However, ending with the first obtained value of coefficient ρ would be in majority of cases only approximation. Therefore Cochrane and Orcutt (1949) suggested an alternative procedure. When applying regression methods to the model given by equation (19), it is possible to get new residuals v_t for which is obtained new estimate of ρ. Transformation of the original model is consequently repeated again with new ρ. With the help of SPSS these iterations are repeated until a change in any of estimated parameters is not higher than 0.001. In consequence, an appropriate value of coefficient ρ is reached.[73]

(19) $$Y_t^* = b_0^* + b_1 X_{t1}^* + ... + b_k X_{tk}^* + v_t$$

where

$$Y_t^* = Y_t - r' \cdot Y_{t-1},\ b_0^* = b_0 (1 - r')\ and\ X_{ti}^* = X_{ti} - r' \cdot X_{(t-1)i}$$

for t = 2, 3, …, n and i = 1, …, k

If ρ was known at the beginning, OLS could be directly applied to the model given by equation (19) in order to obtain efficient estimates. However, since ρ is unknown, one has to follow CORC iterative procedure that is stopped when reaching a predetermined level. The final coefficient r' is then applied to (19) in order to obtain an efficient estimator.

Running CORC procedure, the total number of 8 iterations was reached in SPSS. The transformed model is subsequently estimated in EViews[74] with r' equal to 0.888032 and thus we get appropriate regression coefficients.

---

[72] We just loose the first observation by this transformation what does not cause any trouble since our data set is large enough.

[73] Of course there might be used different conditions, quite frequent is e.g. reaching some difference in values of two subsequent coefficients ρ (e.g. 0.001).

[74] Although the coefficient ρ was obtained in SPSS, this software is not able to provide us GLS estimate with robust standard errors at the same time. Therefore we use EViews that has no problems with providing us necessary robust estimates.

Table 14: Cochrane-Orcutt iterations

Iteration	ρ (AR1)		D-W stat.
	value	***std. error***	
0	0.760916	0.0102	1.655
1	0.858904	0.0081	1.834
2	0.880759	0.0075	1.866
3	0.886222	0.0073	1.873
4	0.887583	0.0073	1.875
5	0.887922	0.0073	1.876
6	0.888006	0.0073	1.876
7	0.888027	0.0073	1.876
8	0.888032	0.0073	1.876

Source: Author

In comparison with OLS, coefficients estimated with GLS are different since GLS leads to the more pronounced coefficient on monthly temperature variable and decrease in the coefficient on actual day's temperature. Therefore it is evident that autocorrelation in residuals in the original model led to overestimated effect of actual day's temperature on current natural gas consumption.

Table 15: GLS regression results

variable	coefficient	coefficient	std. error	t-statistic	p-value
	OLS	**Cochrane-Orcutt**			
const.	413.492	407.049	3.284	123.932	0.000
weekends	-29.606	-24.774	0.439	-56.389	0.000
T_t	-10.961	-6.829	0.110	-61.847	0.000
$T_{(t-1 - t-6)}$	-7.575	-7.135	0.273	-26.098	0.000
$T_{(t-7 - t-30)}$	-2.209	-6.178	0.383	-16.146	0.000
R-Square	0.967	0.728			
adj. R-Square	0.967	0.727			
std. error	25.543	14.323			
F-statistic	28981.932	2678.236			
Durbin-Watson	0.473	1.876			

Source: Author

When performing OLS, the Durbin-Watson statistics indicated strong positive autocorrelation of residuals, which causes R-Square of the model to be overestimated. With usage of GLS, the Durbin-Watson statistics reaches a satisfactory level (rises to 1.876) that indicates a remedy to autocorrelation. Due to corrected autocorrelation, non-overestimated R-Square falls to 72.8%, as it was overestimated due to autocorrelation in the case of OLS. Nevertheless, the explanatory power of the model is still large enough so the model provides us an idea of large dependency of natural gas consumption on temperature.

- ***Robust estimators with GLS***

After dealing with autocorrelation, heteroskedasticity is still present in the model estimated with GLS. As a remedy, robust standard errors are applied again. Based on the results shown in Table 16, there is just a slight difference between White and HAC standard errors and t-statistics. Since autocorrelation has been fixed with GLS, both types of robust estimators serve primarily as a remedy to heteroskedasticity.

Table 16: Robust standard errors with Cochrane-Orcutt

variable	coeff.	s.e.	t-stat.	s.e.	t-stat.	s.e.	t-stat.
		OLS s.e.		*White s.e.*		*HAC s.e.*	
const.	407.049	3.284	123.932	3.955	102.922	3.791	107.364
weekends	-24.774	0.439	-56.389	0.462	-53.607	0.567	-43.659
T_t	-6.829	0.110	-61.847	0.154	-44.238	0.194	-35.163
$T_{(t-1 - t-6)}$	-7.135	0.273	-26.098	0.299	-23.847	0.295	-24.158
$T_{(t-7 - t-30)}$	-6.178	0.383	-16.146	0.407	-15.179	0.378	-16.358

Source: Author

Since both kinds of robust errors are similar, the application of heteroskedasticity robust White standard errors is enough to correctly interpret the results. Because p-values are still very low (<0.000), all the coefficients in the model stay significant. With the help of GLS, we have assessed the impact of weather on daily natural gas consumption, which is not very different in comparison with similar studies that generally estimate the change in consumption by some 5-10% due to a change in temperature by 1°C.

Although our intention was to avoid autocorrelation of residuals, it could be sometimes useful to include also the autocorrelation process in the model (e.g. AR (1)), e.g. to exactly estimate consumption in the short term, that was done for example by Zanotti et al. (2003). On the other hand, this would a slightly different story and since we are interested in assessing the impact of changes in temperature, we do not include autocorrelation into the model.

Therefore it is important to consider in similar models not only the economic point of view, but also the statistical. Since there are commonly present autocorrelated residuals, we should generally deal with this issue. In order to get an efficient estimator and avoid problems with interpretation of results, GLS should be applied to the final model. As we have seen overestimated R-Squares of approximately 90% in Chapter 3.1, it was in all cases due to autocorrelation of residuals, which leads to incorrect interpretation of OLS results.

To sum up, we have demonstrated that temperature greatly influences consumption of natural gas. If a company is not aware of potential threats linked to adverse weather conditions, it may in the end cause large financial losses. With regard to our results, a company may generally choose from two options to ensure stable financial performance:

- implement new findings into contracts with customers[75]
- decide to hedge weather risk in the financial markets

It is obvious that the application of a similar model generally requires continuous actualization with respect to the current situation in the market. As a company may for example loose several significant manufactories (that are temperature independent) creating a high portion of company's portfolio, its performance would become even more susceptible to weather.

Nevertheless, also the results reported by us serve as an evidence of strong dependency of natural gas consumption on temperature. Therefore it might be appropriate for particular companies to protect their businesses against weather risks with the help of weather derivatives, as it is frequently done in the world.

[75] Since companies frequently use off-takes' flexibility bands in contracts with their customers (i.e. that a customer has to off-take at least for example 85% of contracted volumes), some kind of a regression model may be implemented into contracts instead of just a plain percentage.

4. HEDGING WITH WEATHER DERIVATIVES

"Weather hedges provide financial compensation for the buyer when adverse weather occurs. They can be structured to pay out against specific levels of precipitation, temperature or wind, or a combination of those and other weather variables."

Randy Myers*

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 for example temperature, precipitation, snowfall or wind 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?

* Myers, R. (2008): *What Every CFO Needs to Know About Weather Risk Management*.

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.

Because we have already demonstrated the level of weather risk in the Czech market, we focus on the applicability of temperature-based derivatives in this chapter. According to 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.[76]
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.

Because weather hedges are most efficient when they are customized to buyer's specific needs and risk exposure, accurate quantification of potential impacts

[76] 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.

of weather with all associated risks is essential. It is generally recommended to correlate weather, sales and profit data for at least five years backwards. Hereafter an appropriate weather index has to be chosen in order to build a convenient derivative's structure. Since we do not have information on commodity prices, consumption (sales) of natural gas is used for the analysis of hedging capabilities.

4. 1. Weather options

4. 1. 1. Degree days options

♦ ***Usage of temperature indices***

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:

- § Heating Degree Days (HDD)
- § Cooling Degree Days (CDD)
- § Cumulative Average Temperature (CAT)[77]

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.

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

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

degrees by which the daily average temperature is above this value. Mathematically expressed, daily HDD and CDD structures look as follows:

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

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

The base approach in the energy sector, which has been previously used in numerous studies[78], 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.[79] 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 (2000) demonstrate the importance of a cumulative HDD index (see equation (22)), 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

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

[78] For example Alaton (2002), Clemens et al. (2008), etc.
[79] Wikipedia gives an illustrative example on HDD by comparison of two American cities with very different climatic conditions, New York City and Barrow in Alaska. With regard to cumulative HDD over the period of one year, it would require four times more energy to heat a house of a similar structure in Alaska than in New York. Total HDD over one year in Barrow is around 20,000 while it is just about 5,000 in New York City. For more information, look at: http://en.wikipedia.org/wiki/Heating_degree_day.

♦ ***Weather options***

As we have already stated, the most commonly used weather derivatives are options, especially calls and puts[80] as well as their various combinations, e.g. collars[81]. With regard to intentions of particular hedges, a company generally decides on various option types shown in Table 17. 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 17: 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 et al. (2000)

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

In spite of wide flexibility available in designing weather derivatives, basic attributes are mutual for almost all contracts. Therefore several basic features have to be specified to determine the payoff from a HDD option.

§ call option

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

§ put option

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

where

[80] 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.
[81] Collar enables a market player to minimize his hedging costs by buying a put and selling a call with the same strike price.

- *X means the strike level*
- *HDD is an aggregate level of the index*
- *Tick is the payment per one HDD*
- *Cap is the maximum payment from an option*

On the day following the end of a contract period, the payout from an option may be computed in compliance with equations (23) and (24).

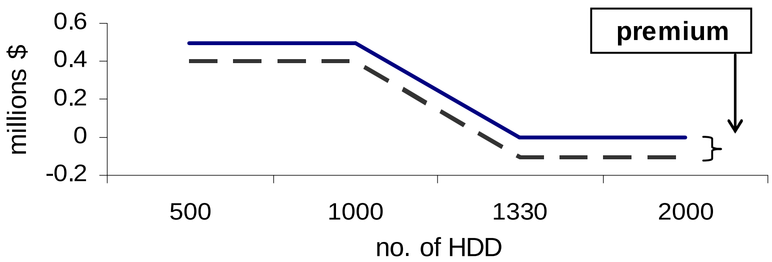
♦ ***Options used by companies trading natural gas***

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 (2002) gives an illustrative example (see Figure 29) 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 29: Payout diagram of a long put HDD option



Source: Dutton (2002)

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.

4. 1. 2. Pricing techniques

"Due to the lack of widely accepted weather derivatives pricing methodologies, counterparties do not always agree on the right price to trade."

Mark Garman [*]

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) 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.

[*] Garman et al. (2000): *Weather Derivatives: Instruments and Pricing Issues*. March 2000.

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 (e.g. the Black-Scholes) 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. 2. Burn analysis

Burn analysis presumes the future development of weather corresponding to the average of its past behaviour. Thus, accordingly to reasonable but only relatively validated prediction, historical data can serve as a predictor of normal behaviour of temperature in the long-term. With regard to the easiness of this method, it may serve as an ideal starting point for a company that is considering purchasing of a weather derivative contract. To find the fair price of a potentially used HDD put option, we follow hereinbefore suggested Nelken's scheme.

Pricing of weather options needs a good source of historical temperature data and further application of statistical methods to fit distribution functions to this data. With the data provided by CHMI that have been already used in Chapter 3, there is no problem with collection of daily temperature measurements. Therefore measurements at station Praha – Ruzyně might without any problems serve a basis for hedging.

♦ ***Transformation into HDD***

When transforming temperature measurements into HDD, one has to decide about the threshold level of temperature (see equation (20)). Despite the market convention of using 18°C, we would suggest, in accordance with the previous chapter, application of 16°C in the Czech natural gas market since it effectively captures heating demand and thus temperature dependent portion of consumption.

In order to build a cumulative HDD function, the risk exposure period, which is commonly considered to be a whole season or a particular month, has to be specified. HDD indices are commonly computed over the "winter season" what in most cases signifies the period from October to April, or November to March.[82]

Table 18: Share of HDD in winter

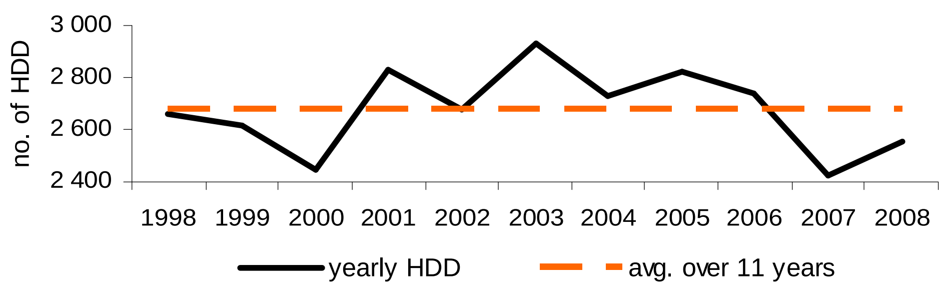
year	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
total HDD	2 826	2 754	2 574	2 991	2 735	2 989	2 918	3 041	2 942	2 531	2 678
winter HDD	2 664	2 618	2 444	2 829	2 675	2 933	2 727	2 826	2 739	2 421	2 554
% of winter	94%	95%	95%	95%	98%	98%	93%	93%	93%	96%	95%

Source: Author

With regard to Chapter 3.2.2 (Figure 21) and our regression results, it could be rewarding to do not use hedging with weather options for the whole year, but just for a part where consumption varies the most. Therefore an effective hedge is suggested to be applied only for the period of eight months, from September, 1 to April, 30. What is more, if we transform temperature data into HDD (with application of 16°C as the base level), one might see in Table 18 that these eight months (labelled as "winter") contain the vast majority of yearly HDD.

Cumulative HDD index for a potentially hedged period (Figure 30) has been obtained by transformation of temperature data. The dashed line, representing the average quantity of HDD in the last eleven years, indicates that buying of HDD put options could have been appropriate in recent warm years. However, the profitability is in the end always a question of hedging costs.

Figure 30: Yearly number of HDD during the hedged period



Source: CHMI

[82] On the other hand, CDD indices are generally used during the "summer season".

♦ ***Payoff structure***

We show the payoff structure of a put option once more.

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

Because the number of HDD for each particular year is well known, especially the exercise level of an option has to be chosen properly. Roustant et al. (2003) suggest employing of the historical average temperature (HDD) index as a basic exercise level whereas e.g. Garcia and Sturzenegger (2001) suggest calculation as the average cumulative HDD minus ½ of its standard deviation. As another method, Platen and West (2004) apply as an exercise level the average cumulative HDD plus ½ of the standard deviation. Hereafter, playing with various levels close to the average HDD is recommended to find out the most appropriate alternative.

Considering temperature measurements over the last eleven years should be appropriate for choosing an exercise level, which is generally set in accordance with the normal climate conditions. Even though there are various approaches to this issue, the market usually takes as normal the average level over the past 10-15 years.[83] Because appropriate descriptive statistics for HDD (cumulated over 8 months) are listed in Table 19, one may show some of possible exercise levels of an option.

Table 19: Statistics on HDD in the Czech Republic (1998-2008)

	min.	max.	mean	std. dev.
HDD	2 421.3	2 932.7	2 675.6	159.9

Source: Author

Garman et al. (2000) suggest the calculation of an expected payoff for each year and consequent application of the average of those historical payoffs as the fair price. Hereafter, we determine the payoff of an illustrative HDD put option for the period of 8 months with the tick of EUR 1,000 per HDD and no payment's cap considered.

[83] Nevertheless, there might be exceptions, e.g. Considine (1999) mentions the case of Miami where 15-years average may not be appropriate as there has been substantial warming trend over the past 30 years.

Table 20: Various payoffs of the option

year	HDD	payoff (EUR)		
		X = 2595,7	*X = 2675,6*	*X = 2755,6*
1998	2 664,3	0	11 300	91 300
1999	2 618,4	0	57 250	137 250
2000	2 444,0	151 700	231 600	311 600
2001	2 829,4	0	0	0
2002	2 675,3	0	300	80 300
2003	2 932,7	0	0	0
2004	2 727,5	0	0	28 150
2005	2 826,2	0	0	0
2006	2 739,3	0	0	16 311
2007	2 421,3	174 400	254 300	334 300
2008	2 553,7	42 000	121 900	201 900
average	***2 675,6***	***33 464***	***61 514***	***109 192***

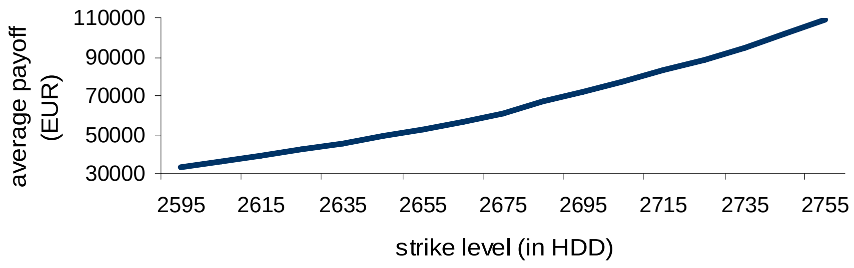
Source: Author

In Table 20 are displayed payoffs of the option with application of exercise levels suggested by:

- Garcia and Sturzenegger (2001): exercise level = average HDD - ½ of std. dev.
- Roustant et al. (2003): exercise level = average HDD
- Platen and West (2004): exercise level = average HDD + ½ of std. dev.

Calculation of average payoffs from the option in the past provides primary idea on value of the option. If a company is able to find such an option whose costs are similar of lower than above listed prices, it may be an indicator to look at that option in more detail. The logic of HDD put option pricing is straightforward: with increasing exercise level (and no cap on payments considered) raises also the average payoff of the option (as shown in Figure 31).

Figure 31: Average payoff with regard to various exercise levels



Source: Author

Burn analysis is one of the primary steps on the way to hedging against weather risk. Both assessing of weather sensitivity of a business and searching for hedging possibilities, in which is frequently involved also burn analysis, should provide a notion whether it could be favourable to protect company's financial performance with weather derivatives.

However, when it is the time to make a final decision, more sophisticated methods are generally applied for pricing weather derivatives. Since a company determines the fair price of a hedge and is able to find such a financial instrument, which corresponds to this fair price level and satisfies all requirements of a company, the only question remains: *"How many weather options to buy?"* This question is generally answered with regard to size and weather sensitivity of company's revenues.

♦ CONCLUSION

Since the natural gas market in Europe is going through the process of liberalization, companies become aware of controlling their revenues more than ever. It is weather risk that highly influences stability of revenues in the natural gas business. Although companies in regulated markets were commonly adjusting prices to offset low revenues in the case of decreased demand for heating, the approach to this issue has greatly changed since the 90's as ongoing deregulation made increasing of consumer prices difficult.

Therefore it was primarily the interest of energy companies in the U.S. that helped the new weather risk market to emerge in the 90's. With the aim of staying competitive in liberalized markets, companies started to assess impacts of weather on their financial performance and consequently hedge against weather risk.

With a wide scale of opportunities in hedging against weather risk, energy companies commonly undertake analyses of weather sensitivity of their businesses and the favourableness of potential hedging. This unambiguously holds for companies trading natural gas since consumption of this commodity is highly affected by changeable weather, especially by temperature. Among the most frequent methods of evaluating the dependency belong consumption models on which is applied OLS regression method. In this thesis, we have built such a model that estimates the impact of weather on natural gas consumption in the Czech Republic.

By addition of several useful features, we have been successively improving the explanatory power of the model, which considers daily natural gas consumption as the dependent variable. Absolutely fundamental in the majority of similar studies is application of two basic explanatory variables:

- actual day’s temperature
- the impact of weekends and bank holidays

Both increasing temperature on the actual day and the presence of weekend may cause a significant fall in natural gas consumption. The explanation is straightforward since higher temperature is generally reflected in lower consumption as the heating requirements fall. Considering the impact of weekend, industries usually consume lower volumes during weekends due to limited production.

We have demonstrated that in the Czech market is present approximately linear relationship between natural gas consumption and temperature with an exception during warm periods of the year. With temperatures above some threshold level, there generally remains only the base-load consumption, which is primarily comprised by demand of industrial customers and is not dependent on temperature. Such a feature is in various forms common for all natural gas markets. When comparing several levels of temperature, we have decided to set the cap on temperature at 16°C that effectively reflects heating requirements. By this transformation, the model assigns to all observations with temperature higher than 16°C the same consumption, which corresponds to the fact that consumption stays with high temperatures close to mentioned base-load level.

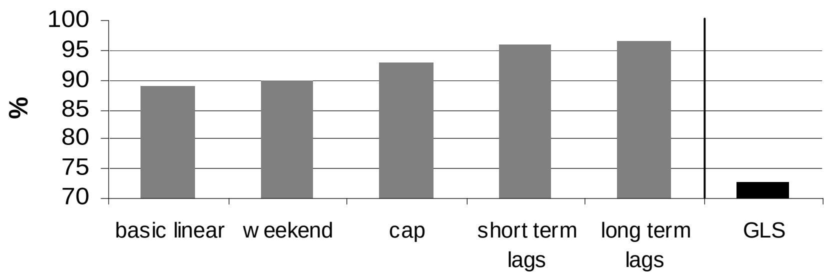
The last characteristic that we implemented in the model is the impact of past days’ temperatures. It is a common practice that several lagged values of temperature are included in similar models, for example Zanotti et al. (2003) used in their model two foregoing days, which primarily reflect the need for adjustment of heating devices in the short term. However, we have taken into account in our final model also the adjustment of heating devices in the long term.

Since manufactories generally adjust (or even turn off) their heating devices with regard to some long term temperature profile, we have included in the model as explanatory variables the weekly and monthly averages of daily temperatures. In comparison with frequent application of temperatures on directly preceding days, we have improved the explanatory power of the model and also avoided unfavourable problem of multicollinearity, which occurred with application of only short term lags. What is more, the coefficients of both short and long term temperature averages are highly significant and not small. Therefore it should be useful for similar studies to include the long term temperature profile to model natural gas consumption effectively. However, it is not a common practice in similar studies or even in analyses of natural gas companies.

When investigating the residuals of our final model, the presence of both autocorrelation and heteroskedasticity was revealed that caused the OLS estimator to be inefficient. Because the OLS estimator is unbiased, the model would be with application of robust standard errors, which deal with heteroskedasticity and autocorrelation, satisfactory for the majority of natural gas traders.

Nevertheless, we have decided to use the generalized least squares method (with the Cochrane-Orcutt transformation) in order to deal with the autocorrelation of residuals and consequently get an efficient estimator. Furthermore, robust standard errors and t-statistics were applied as a remedy to heteroskedasticity problem. Consequently, correct result for R-Square (of 72.8%) was obtained because the result of OLS was overestimated due to present autocorrelation. Even the GLS results signify that the model still highly explains variations in daily natural gas consumption by changes temperature.

Figure 32: Comparison of applied methods (R-Squares)



Source: Author

Building of such a model, which assesses the impact of weather (temperature) on a business, generally greatly helps to predict natural gas consumption. What is more, a quality model can be consequently applied for example in contracts with customers, e.g. to set flexibility bands in daily, monthly or yearly off-takes. Finally, evaluation of the dependency frequently serves also as the first step when considering hedging against weather risk, for which are commonly used weather derivatives that emerged in the 90's.

Weather derivatives applied for the purpose of natural gas companies are generally HDD put options, which serve especially as a protection against abnormally high temperatures in winter. Beside some other factors, the final decision on hedging is commonly done with regard to a cost benefit analysis. Despite the fact that there exist even more sophisticated methods of assessing the fair price of an option, we have performed so called burn analysis that often serves as the first indicator of the fair price of an option. If revenues from the hedge are higher than costs, by which is meant an option premium, it is a good indicator that the hedge could be convenient. Therefore a company is generally looking such a hedge whose costs are below the fair price.

♦ Appendix: The Ordinary Least Squares

The most common method used by econometricians is the Ordinary Least Squares (OLS) method or its numerous variations (like e.g. Generalized Least Squares are), that fit a curve to input data in a way that minimizes the sum of squared residuals from all particular observations to the model's line. Although it is not extremely difficult to run the OLS regression even for large datasets, special care should be given to identification of:

- influential observations (= outliers)
- correlation across variables
- error terms' patterns
- other various biasing influences

Although there may be no problems with the variables, one needs to be aware primarily of the structure of error term (disturbances). In order to reach BLUE when applying the OLS regression method, specific assumptions about disturbance have to be satisfied:

- zero mean disturbances
- constant disturbances' variance of σ^2
- disturbances have zero covariance, i.e. there is no autocorrelation among them

If these assumptions do not hold, an estimator is not necessarily BLUE. Consequently changing of a specification or even changing of the whole estimation method is not an exception.

When all the particular tests for possible problems are successfully carried, the model is specified correctly and the error term distributed normally around a zero mean, the regression results (i.e. estimation coefficients) may interpreted.

♦ ***Problems with OLS***

As the most prevalent problems with the OLS are considered to be the following issues regarding:

1) explanatory variables

a) Multicollinearity

This problem threats whenever there is more than one explanatory variable as two or more variables may be explaining the dependent variable well, but at the same time be closely correlated with each other. As a consequence, it is difficult to distinguish explanatory effects of particular variables. Multicollinearity generally causes low significance of individual coefficients or increasing standard errors of the coefficients (although this is not just a consequence of multicollinearity alone).

b) Outliers

OLS is highly sensitive to the outliers, i.e. very different observations usually caused by some extraordinary factor. Despite the fact that it could be suitable to omit these observations from the regression, they may provide useful information and do not be outliers at all.

c) Missing variables

If we omit some important variable, included regression estimates tend to be biased. On the other hand, if we add into the regression variables that are not useful, it only causes that the variance is not minimal. Therefore it is should be generally less harmful to add some useless variable into the regression than omit an important one.

Besides, it is always important to look also at the residuals' randomness. Even though the model may look well since there is no problem with the variables, the results may be misleading.

2) disturbances

a) Autocorrelation of disturbances

In this case, the zero covariance between disturbances is violated what causes that the OLS is not the best estimation method since the true variance is underestimated. There exist several features that produce auto-correlated error terms, e.g. omitting of some important variable, misspecification of the functional form or non-randomness of errors. Autocorrelation of disturbances is generally tested with Durbin-Watson Statistic or with more general Breusch-Pagan LM test.

In the regression, if noise is AR (1) process, a simple estimate of the Durbin-Watson value ρ is obtained by regressing ε_t onto ε_{t-1} and thus:

$$\hat{r} = \frac{\sum_{t=2}^{n}(e_t \cdot e_{t-1})}{\sum_{t=1}^{n} e_t^2}$$

To test the hypothesis H0: $\rho = 0$, i.e. that residuals are independent against HA that they have AR (1) form, we use Durbin-Watson test based on coefficient:

$$d = 2 \cdot (1 - \hat{r})$$

b) Heteroskedasticity

Heteroskedasticity signifies violation of different OLS assumption – constant variance of disturbances, which causes standard errors of estimated coefficients to be biased. Since standard errors are underestimated in the presence of heteroskedasticity, some of explanatory variables may seem to be significant in the model whereas they are not. In this thesis, I apply White's test when searching for heteroskedasticity in the model.

If it is revealed that the assumptions are not fulfilled by the nature of the data, robust regression methods or nonparametric regression analysis generally provide alternatives to the OLS.

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DIPLOMA THESIS PROJECT

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Consultant: **Mgr. Tomáš Václavík**

Topic:

Weather Risk on the Gas Market

Characteristics of the Topic:

Weather risk is the uncertainty caused by weather volatility. Many energy companies look at weather as one of the main sources of their financial insecurity since weather changes significantly influence demand for products on the energy markets, especially during the winter months.

In this thesis, I would like to give attention to the gas market. Using statistical models I will investigate how temperature changes affect gas demand. Based on the results of these models, I would like to identify and analyze risks linked to temperature changes.

In the final part of this thesis, I would like to search whether there are the need and possibilities to hedge these risks on the gas market. Around the world, financial derivatives are used to it although they practically did not exist before the middle of 90s.

Hypothesis:

- Regression models estimate well dependency of gas demand on weather changes.
- Risks can be relatively well quantified.
- Introducing of hedging could be useful.

Working Procedure:

- Statistical models investigating dependence of consumption on temperature.
- Subsequent analysis of risks resulting from weather changes.
- Market analysis of hedging possibilities.

Expected Content:

- Introduction
- Weather risk on energy markets
- Gas market in the Czech Republic
- Effect of weather changes on gas demand
  - dependencies
  - risk evaluation
- Weather risks hedging
- Conclusion

Basic Sources:

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supervisor author