ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF ART AND SOCIAL SCIENCES

AN ECONOMETRIC MODEL OF FUTURE PRICES AND STORAGE RELATIONSHIP IN THE NATURAL GAS MARKET

M.Sc. THESIS

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DOĞAL GAZ PİYASASINDA GELECEKTEKİ FİYATLAR VE DEPOLAMAYA İLİŞKİN BİR EKONOMETRİK MODEL

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Tolga YAKAN, a M.Sc. student of ITU Graduate School of Art and Social Sciences student ID 412101020, successfully defended the thesis entitled "An Econometric Model of Future Prices and Storage Relationship in the Natural Gas Market", which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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FOREWORD

This thesis is written as a requirement for the Master’s degree in Economics at the Institute of Social Sciences of Istanbul Technical University.
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ABBREVIATIONS

App	**:** Appendix
BP	**:** British Petroleum
CIEP	**:** Clingendael International Energy Programme
EIA	**:** U.S Energy Information Administration
EMRA	**:** Energy Market Regulatory Authority
IPCC	**:** International Panel of Climate Change
TPC	**:** Turkish Petroleum Corporation

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AN ECONOMETRIC MODEL OF FUTURE PRICES AND STORAGE RELATIONSHIP IN THE NATURAL GAS MARKET

SUMMARY

The widespread use of natural gas in many countries is mainly due to heating needs and electricity generation. Many countries display a tendency to increase their electricity production from natural gas, because it is environmentally friendly and cheaper than the other fossil fuels, such as oil. Natural gas can be found within a country's borders or it can be imported from abroad. In either case, the released gas from reservoirs should be carried with pipelines to the certain point. After this point, there are some options to operate natural gas for different purposes. Storage is one of the options to manage natural gas for efficient usage in the future, and it is also vital for adapting to the unexpected conditions in the gas market. In addition, natural gas storage is crucial for influencing fluctuations in gas supply and demand and it reduces the effect of some significant differences in supply and demand. Due to such possible fluctuations in demand and supply, natural gas should be stored, because storage is the most natural source of flexibility in gas sector.

In recent years, Turkish total primary energy demand increased depending on industrial developments and residential energy consumption. Consumption was 98 Mtoe in 2001 and is expected to reach 308 Mtoe in 2020. The major markets in Turkey for natural gas are electricity production and feedstock use. Also, the residential sector is a crucial participant of the natural gas market as the network has been extended to new cities. Both the government and the state natural gas distributor company -BOTAS- are well aware of the need for further diversification of gas supplies and the need to develop storage facilities.

For the purposes above, this thesis builds up an empirical model of future prices based the Theory of Storage. As one of the most complete models in the literature, the difference between future and current spot prices are a function of interest rates, risk premium, storage cost, and the convenience yield. Furthermore, the variable risk premium is separately estimated and the variable convenience yield is proxied using three different price and storage related variables. In particular, conveience yield depends on price shocks, volatility, and storage shocks, which proxy storage capacities. Remarkably, main findings confirm each prediction of the Theory of Storage and provide us with coefficients that enable to forecast future prices. In particular, the difference between future and current spot prices increases with shocks to storage, which proxy storage capacity. This result suggests some speculative behavior especially with too high levels of storage.

DOĞAL GAZ PİYASASINDA GELECEKTEKİ FİYATLAR VE DEPOLAMAYA İLİŞKİN BİR EKONOMETRİK MODEL

ÖZET

Dünya doğal gaz tüketiminin son yıllarda hızlı bir artış içerisinde olduğu görülmektedir. Son dönemde, ısınmanın yanı sıra enerji santrallerinde de yoğun bir şekilde doğal gaz kullanımının artması, doğal gaz tüketiminin dünya enerji kaynakları içerisinde de payının artmasına sebep olmaktadır. Doğal gaz kullanımına yönelik olan bu eğilimin temel sebepleri olarak doğal gazın diğer fosil yakıtlara oranla daha temiz bir yakıt olması, ayrıca benzer ısıl kapasiteye sahip diğer yakıtlara göre daha ucuz oluşudur. Doğal gaz, santrallerde ekonomik olarak türbünlerin etkinliğini sağlamasına yardımcı olur. Ayrıca yakıldığında, kömür ve petrole göre daha az sülfür dioksit, karbon dioksit ve atık açığa çıkmaktadır.

Enerji giderleri bir çok ülke için temel giderler arasında önemli bir yer teşkil etmektedir. Özellikle yerli enerji kaynakları yetersiz, enerji ihtiyacını ithalat üzerinden sağlamak zorunda olan ülkeler açısından bu durum daha da önem taşımaktadır. Türkiye de yerli enerji kaynakları yetersizliği yüzünden enerji ihtiyacının büyük bir kısmını ithalat üzerinden sağlayan ülkeler kategorisindedir. Özellikle son yıllarda, doğal gaz ve elektrik talebinin yüksek oranlar ile seyretmesi Türkiye'yi enerji tüketimi açısından çıkmaza sokmaktadır. Bu durum bilhassa kalkınma sürecinde olan Türkiye'nin önünde önemli bir engel oluşturmaktadır. Türkiye'nin son yıllarda elektrik üretiminin büyük bir kısmını doğal gazdan sağlaması, aynı zamanda mevcut şehirler dışındaki diğer şehirlere olan doğal gaz altyapı çalışmaları ve ileriyi öngörerek yaptığı enerji politikalarına bakıldığında enerji ile ilgili yapılacak her türlü gelişimin önemini ortaya koymaktadır. Bu süreç içerisinde yapılabilecek önemli gelişim aşamalarından biri ise yeraltı doğal gaz depolama alanlarının sayısının artırılması gelmektedir. Türkiye sahip olduğu yeraltı depolama tesisleri bir çok gelişmiş ülkenin gerisinde kalmaktadır.

Doğal gazda da diğer fosil yakıtlarda olduğu gibi üretilen doğal gaz üretim bölgesinden borular yardımı ile kullanılması planlanan bölgeye taşınmaktadır. Borular yardımıyla taşınan bu doğalgaz ulaşılmak istenilen noktaya geldikten sonra farklı amaçlara bağlı olarak kullanılabilmektedir. Doğal gazın depolanması bu noktadan sonra düşünülmesi gereken bir sistemdir ve doğal gaz depolama işlemi farklı yollarla gerçekleştirilebilir. Tez içerisinde incelenmesi planlanan depolama sistemleri ise doğal gazın yeraltında depolanmasına imkan veren depolama sistemleridir. Yeraltı doğalgaz depolama sistemleri içerisinde; tüketilmiş doğalgaz veya petrol rezervuarları, akiferler ve tuz mağaraları bulunmaktadır. Son dönemde var olan bu sistemlere ek olarak yapay tuz mağaraları da geliştirilmeye çalışılmaktadır. Fakat, yapay tuz mağaraları, teknolojisinin daha yeni gelişmekte oluşu ve mevcut örneklerinin yeteri miktarda olmaması sebebiyle bu çalışmada değerlendirilmeyecektir. Diğer bir depolama tarzı olan ve teknolojik açıdan diğer

yeraltı depolama tesislerinden farklılıklar gösteren LNG (sıvılaştırılmış doğal gaz), literatürde yapılan benzer çalışmalarda yeraltı depolama tesisi olarak kabul görmemesinden dolayı bu tezde de yeraltı doğal gaz depolama sistemleri içerisinde değerlendirilmeyecektir.

Tüketilmiş gaz veya petrol rezervuarları yeraltı doğalgaz depolama tesisleri arasında en çok kullanılanıdır. Yatırım maliyetleri açısından diğer depolama tesislerine göre daha az bir finansmana ihtiyaç duymaktadır. Bunun yanı sıra depolamanın teknik ihtiyaçları ve tesisin işletimi açısından da diğer depolama tesislerine göre daha kolay uygulamaları olan bir sistemdir. Ek olarak, tüketilmiş gaz veya petrol rezervuarları doğal gazın tüketim bölgesine yakın olması alt yapı maliyetlerinin dezavantaj oluşturmaması açısından önem taşır.

Akiferler de kurulması planlanan bölgenin jeolojik yapısına bağlı olarak gerçekleştirilebilecek yeraltı doğal gaz depolama sistemlerindendir. Teknik özellikleri açısından tüketilmiş gaz veya petrol rezervuarlarına benzemekle beraber, doğal gazın dağıtabilirliği, içerisinde bulanan aktif su hareketlerine bağlı olarak değişmektedir. Yatırım maliyetleri açısından da diğer yeraltı doğalgaz depolama sistemlerine göre daha fazla finansmana ihtiyaç duymaktadır.

Tuz mağaraları sahip olduğu boşluklu yapı sayesinde yüksek miktarlarda doğal gaz depolama kapasitesine sahiptir. Diğer yeraltı depolama sistemelerinden daha yüksek enjeksiyon ve çekiş oranlarında çalıştıkları görülmektedir. Tuz mağaralarının en önemli özelliklerinden biri ise yeraltı doğal gaz depolama tesislerinde mutlaka bulunması gereken tampon gazın, miktar bakımından diğer yeraltı doğal gaz depolama çeşitlerine göre daha az miktarda ihtiyaç duymasıdır. Bu durum tampon gaz için gereken maliyetin diğer depolama çeşitlerine göre daha az olması anlamına gelir. Ayrıca tuz mağaraları enjeksiyon ve çekiş hızları açısından da diğer yeraltı depolama sistemlerine göre avantaj sağlamaktadır.

Depolamanın modellenmesi noktasında literatürde farklı çalışmalar yer almaktadır. Depolama ile ilgili yapılan ilk çalışmalarda farklı ürünler üzerinden modellemelere gidilmiştir. Daha sonra enerji kaynakları üzerinde yapılan çalışmalarda da, daha önce farklı ürünler üzerinden yapılan çalışmalarda da görülen ortak nokta, depolamanın ek bir maliyet unsuru getirdiğidir. Başlangıçta katlanılan bu maliyet, depolamanın daha sonraki periyotlarda kazanç getireceği beklentisinden kaynaklanmaktadır. Bahsedilen bu kazanç depolamanan ürünün ileriki periyotlarda gerçekleştirilen satışından elde edilmesi düşünülen kar olarak ifade edilmektedir. Bunun dışında yapılan çalışmalarda üzerinde durulan önemli noktalardan bir diğeri ise depolama miktarı olmaktadır. Depolama miktarı ürünün özelliklerine göre değişmektedir. Özellikle ilk vurgulanan depolama maliyeti ve depolamadan elde edilen kazanç, depolama miktarı ile sıkı bir ilişki içerisindedir. Öngörülen genel düşünce, depolama miktarı ile depolama maliyeti arasında doğru orantılı bir ilişki olduğu, depolamadan elde edilecek kazanç ile depolama miktarı arasında ters orantılı bir ilişki olduğudur. Bu belirlemelerden sonra literatürdeki çalışmalarda değinilen bir sonraki nokta ise yukarıda ifade edilmeye çalışılan unsurların fiyatlarla olan Doğal gazın depolanmasının farklı avantajları mevcuttur. Mevsimsel tüketim farklılıklarının azaltılması, arz ve talep şoklarına karşı doğalgaz piyasasının dayanımının artırılması, fiyat dalgalanmalarının azaltılması gibi özellikler doğalgazın yeraltında depolanmasının amaçları arasında sayılabilir. Burada doğal gazın yeraltı depolama tesislerinde depolanmasının fiyat üzerindeki etkisi farklı durumlara bağlı olarak değişim göstermektedir. Mevsim koşullarındaki keskin geçişler bu konuda örnek gösterilebilir. Ayrıca, para politikalarındaki değişimler ve depolamanın risk getirisinin yüksek olacağı durumlar, depolama sonrasındaki fiyatları etkileyebilecek diğer unsurlar olarak literatürde yer almaktadır.

Tez kapsamında gelecekteki doğal gaz fiyatları ile bu günkü spot fiyatlar arasındaki farkı Depolama Teorisi ışığında ekonometrik olarak modellenmiştir. Bu çerçevede fiyat farkı faiz oranı, depolama maliyeti, risk primi, ve depolama kazancının bir fonksiyonudur. Literatürdeki diğer modellerden farklı olarak Depolama Teorisinin gerektirdiği tüm değişkenler modelde yer almıştır. Ayrıca hem risk primi ayrı bir modelle kestirilmiştir ve depolama kazancı da fiyat şokları, değişkenliği ve depolama şokları ile temsil edilmiştir. Bulgular Depolama Teorisinin her bir tahminini doğrulamaktadır ve model gelecekteki fiyatları tahmin edebilecek katsayılar sunmaktadır. Özelde ise, gelecekteki ile bugünkü fiyatlar arasındaki fark depolama kapasitesini temsil eden depolama şokları değişkeni ile artmaktadır. Bu sonuç özellikle çok yüksek depolama kapasitesi olan durumlarda spekülatif davranışlar olabileceğine işaret etmektedir.

1. INTRODUCTION

The widespread use of natural gas in many countries is mainly due to heating needs and electricity generation. As it is seen in Figure 1.1, the natural gas consumption increases year by year in all around the world. Many countries display a tendency to increase their electricity production from natural gas, because it is environmentally friendly and cheaper than the other fossil fuels, such as oil. (Karasalihovic et al, 2003) The comparisons of different fossil fuels through the emission factors in Figure 1.2 present that the environmental impacts of natural gas is lower than the other ones. Natural gas consists of a high percentage of methane and some heavier hydrocarbons, but before the end-user consumption, some components are removed from the natural gas and this process decreases the share of heavier hydrocarbons. At the end, a uniform and environmentally high quality natural gas is attained. (Banks, 2003) The CO2 dissemination in natural gas is the least among all fossil fuels. (Dresselhaus, Thomas, 2001)

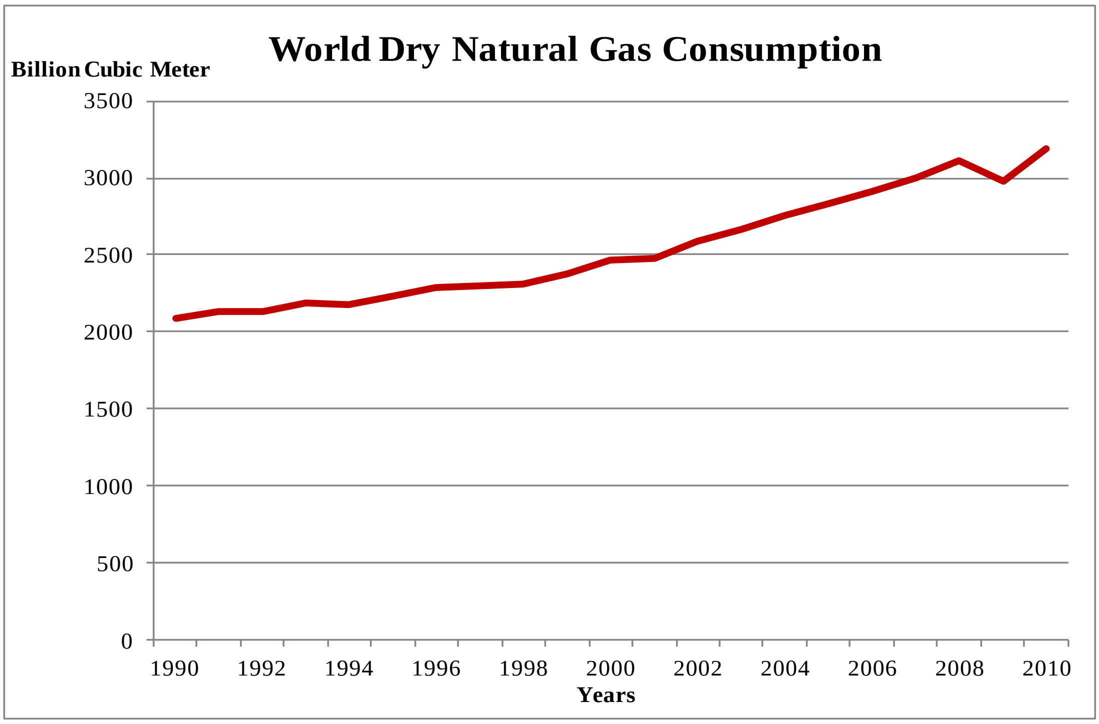

Figure 1.1: World Dry Natural Gas Consumption (EIA)

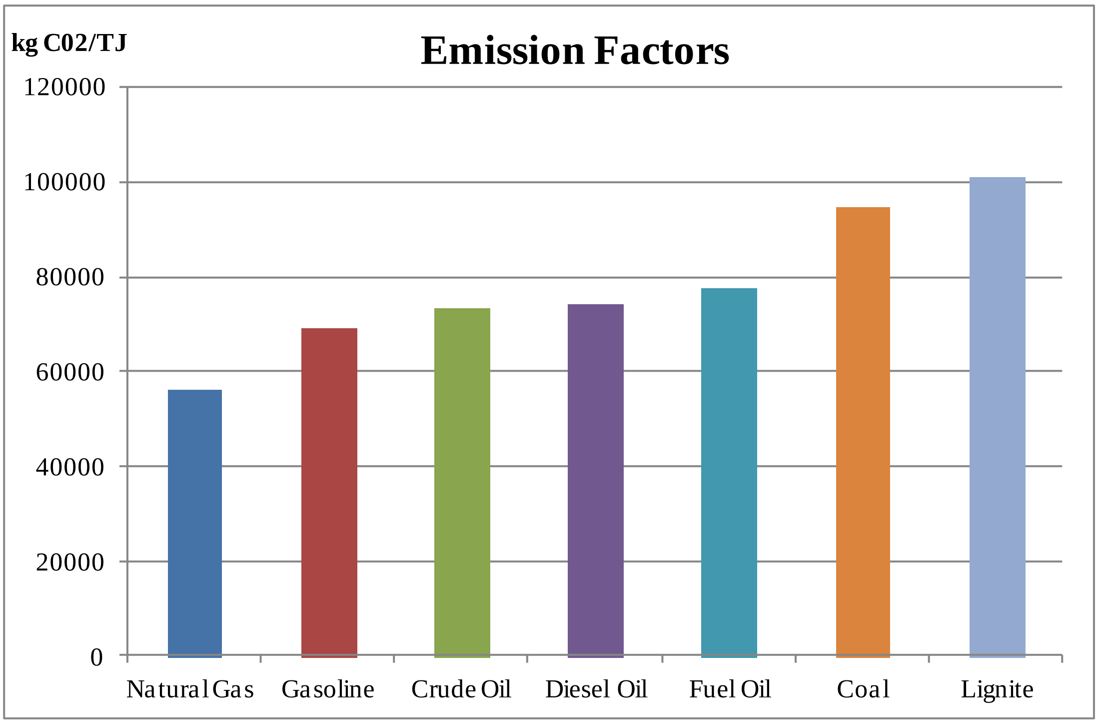

Figure 1.2 : Emission Factors of Fossil Fuels (IPCC)

Natural gas market is based on four main vertically related components. These are production, transmission, storage, and distribution. For instance, the gas may be produced from wells in a gas field in the Caspian Sea region, and it may be transported with a pipeline to a gas terminal in Turkey. Finally, it is either stored or distributed to final consumers, who use the natural gas to generate electricity or for residential purposes. Natural gas can be found within a country's borders or it can be imported from abroad. In either case, the released gas from reservoirs should be carried with pipelines to the certain point. After this point, there are some options to operate natural gas for different purposes. Storage is one of the options to manage natural gas for efficient usage in the future, and it is also vital for adapting to the unexpected conditions in the gas market. Also, gas demand is related with time patterns, such as daily, weekly, or seasonal. (Joode, Özdemir, 2010) On the other hand, some variations in gas supply can exist due to interruptions that occur in the production period. Natural gas storage is crucial for influencing fluctuations in gas supply and demand and it reduces the effect of some significant differences in supply and demand. (Thompson et al, 2009) A major source for providing the flexibility is more gas production in the long term, but generally, it is not possible for every country, so storage can be a good solution in the short term. Fluctuations of supply and demand are typically results of high gas consumption for heating purposes in winter months and high electricity generation in the summer time. (Thompson et al, 2009) Due to such possible fluctuations demand and supply, natural gas should be stored, because storage is the most natural source of flexibility in gas sector. (Chanton et al, 2008) In addition, storage can be used to decrease these market challenges.

There are four types of storage:

i. depleted gas or oil fields,
ii. aquifers,
iii. salt cavern, and
iv. liquefied natural gas (LNG) tanks, which we further discuss below.

Each type has its own economic and physical characteristics, and there is consensus that an optimum amount of storage leads to lower and more stable prices by eliminating excess supply or excess demand. (Banks,2003) This thesis empirically investigates the end use price effect of aggregate storage level for these different underground storage types. For this purpose, we use state-level price and storage data from the United States. We next discuss economic differences in storage types.

In particular, storage facilities are classified according to flexibility in withdrawal and injection, i.e. (high or low withdrawal and injection rates). The two main categories are ‘high deliverability’ sites (salt cavern reservoirs and LNG storages) and seasonal supply reservoirs (depleted fields and aquifers). (Chanton et al, 2005)

Of the three types of underground storage, depleted reservoirs, on average, are the cheapest and easiest to develop, operate, and maintain. Furthermore, gas can be injected into reservoirs that have suitable pore space, permeability, and retention characteristics. (Öztürk, 2003) Basically, the depleted reservoirs are composed of rock with enough porosity so that hydrocarbons can accumulate in these pores, and they have a less permeable layer of rock above the hydrocarbon-bearing stratum. (Öztürk, 2003) The disadvantage of depleted reservoirs is that they must be relatively close to consuming regions; otherwise, the installation of connecting pipelines may need more expense. (Öztürk, 2003) They must also be close to transportation infrastructure, including trunk pipelines and distribution systems.

Aquifers have strong relation with the geography. Generally, in aquifers, natural gas is injected into water bearing reservoirs so that gas can be kept in place by the geometry of structural closure and water pressure. The technical specifications of aquifers, which are volume, injectivity, deliverability, and cycling, tend to be similar to the depleted reservoirs, but the only deliverability may vary with the active water drive. (Bankes,Gaunce, 2009) The disadvantage of aquifer is that they are often most expensive type of the storage facility to operate. (US Department of Energy, 1996) The reasons for high cost are that aquifers need more infrastructure constructions, a longer development period, more cushion gas, closer management of injection and withdrawal. (Bankes,Gaunce, 2009)

Among the high deliverability storage types, salt caverns are located in the producing regions, and they are growing in the U.S due to their deliverability. One of the advantages of salt cavern is that the large amount of gas can be delivered quickly from the salt cavern. This may occur due to two reasons. First, salt caverns have high injection and withdrawal rates. Second, salt cavern facilities operate under very high pressure. Thus, salt cavern are able to respond rapidly to changes in demand or supply. The other advantage of salt caverns is that they need less base gas than other underground storage types. This condition provides more working gas volume, which represents the volume of gas that can be delivered to customers. Thus, capital costs related with salt cavern facilities could have been obtained. (US Department of Energy, 1996) The cycling performance of the salt caverns are also better than the other types of underground natural gas storage, it is up to 6-12 cycles per year. The disadvantage of salt cavern is that it is relatively expensive and differs from the conversion of depleted fields and aquifers.

As discussed above, every underground gas storage reservoir has different characteristics, such as geological, engineering conditions or usage differences. However, some technical descriptions of these storage types are similar to each other. For example, the maximum amount of natural gas that can be stored is defined as total storage capacity. The total storage capacity is divided into two components. The first component of the total storage capacity is called cushion (base) gas, which is used as permanent inventory in a storage facility. (Rumbauskaite, 2011) The task of cushion gas is to manage the pressure and deliverability rate in the facility. The working gas is second component of the total storage capacity that is being operated in the storage facilities. (Rumbauskaite, 2011) The measure of both cushion and working gas show the volume of underground gas reservoirs, and their ratio is not fixed at any given time. This is because the amount of the gas volume important to adjust of injection and withdrawal rates. Also, the volume of cushion gas and working gas can be changed by the equipment and operational parameters. (Rumbauskaite, 2011)

Many countries are located far away from gas fields, and natural gas transportation with pipeline can be an expensive for the long distances. LNG is an alternative storage type for natural gas, and also transportation. Recently, it became more popular than other storage types, because using LNG as also a fuel is a preferred solution for ships and road vehicles, which commonly are large polluters. There are some different costs to import LNG. First of all, the main cost of LNG imports is the purchase cost from the producer. Then, the transport cost, which depends on distance and transportation vehicle, is another significant cost component variable to import of LNG. Lastly, cost of the terminal, which receives and stores, affects the total cost of LNG import. (Hansson, 2008) The total cost of LNG varies in proportion to these parameters.

Time-cost related economic characteristics of natural gas storage include long lead-time, high capital and irrevocable investment. The initial investments provide a large part of the long-run costs. The lead-times for investment in gas storage facilities are considerably large and can vary from 1-5 years for a cavern, 5-8 years for a depleted gas field, and up to 10-12 years for aquifer. (Joode, 2009) The long construction period and investment cost of storage decreases the attractiveness of the investment, but in the long term storage could be solution for important variations in the supply and demand.

In recent years, Turkish total primary energy demand increased depending on industrial developments and residential energy consumptions. It was 98 Mtoe in 2001 and it is expected to reach 308 Mtoe in 2020. (Kiliç,2005) (1000 m^3 NG ~ 0.90 metric tonnes oil equilavent) The dry natural gas consumption of Turkey shows the similar pattern with its total energy consumption. As it can be seen in Figure 1.3, the natural gas consumption also rises in the last decade, and it is expected to increase in the future. There are several factors, such as population growth, economic performance, import and export rates, that are considered to be important for predicting the future energy policies. (Hacisalihoglu,2008)

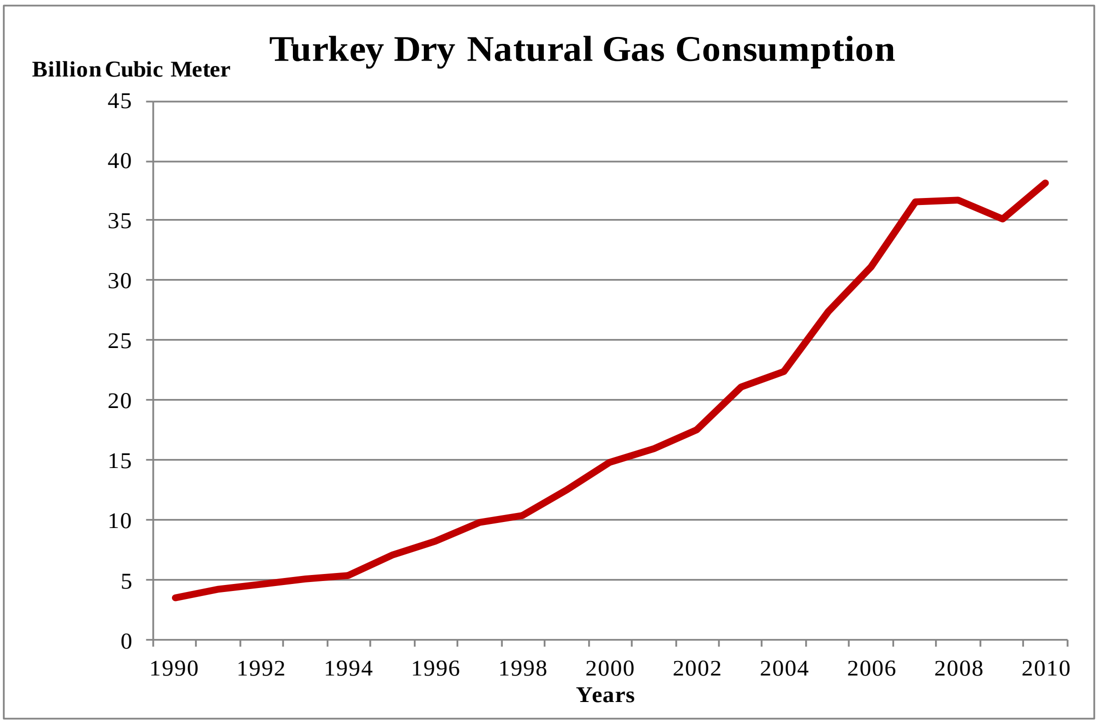

Figure 1.3: Turkey Natural Gas Consumption (EIA)

Turkey is an importer country for primary energy, because its reserves are not sufficient. Countries that export to Turkey include Azerbaijan, Egypt, Iran, Iraq, Russia and Turkmenistan. The rate of gas received from Russia is high in proportion to the other ones. For this reason, Turkey would like to diversify its import sources and has signed new gas import deals. (Hacisalihoglu,2008)

In recent years, the major markets for natural gas are electricity production and feedstock use in Turkey. Also, the residential sector is a crucial participant of the natural gas market as the network has been extended to new cities. (Ozturk,Hepbaslı,2002) More importantly, natural gas is one of the significant sources, in electricity generation in Turkey. According to the Energy Market Regulatory Authority (EMRA) Report (2010), the share of natural gas in total electricity production is almost half of total production in 2008. Moreover, the ratio of natural gas in total electricity production tends to increase in the future period.

Natural gas is Turkey's chosen fuel for new power plants for several reasons. Firstly, natural gas is generally prefers than coal, lignite, or oil due to the environmental results. Recently, there is a resurrection of coal based plants due to developmet of efficient clean technologies, but still the level of operating expertise required for their economic competitiveness has not been solved. (Smolinski,Howaniec,2010). Secondly, the geographic location of Turkey is very close to the natural gas resources such as the Middle East, Russia and Central Asia. Thirdly, Turkey gets some transit fees and charges for oil and gas. Lastly, some politic issues are important, because Turkey tries to develop its relation with the Casparian and Central Asia countries, which are the big gas exporters. (Kiliç,Kaya,2005) The production of natural gas in Turkey is around four percent of domestic natural gas consumption needs. This volume of natural gas is significantly lower than total Turkish demand.

Both government and BOTAS are well aware of the need for further diversification of gas supplies and the need to develop storage facilities. (Ozturk,Hepbaslı,2002) The first underground storage facility is put into service by TPAO in 2007. TPAO's storage has two reservoirs and one of them is Kuzey Marmara Field which has a depth of 1200 meters and discovered in Marmara Sea in 1988, and the other one is Değirmenköy Field which is a depth of 1100 meters and discovered in 1994. The total volume of both storage facilities is 2.661 billion m^3. (TPAO,2012) On the other hand, new projects like Tuz Lake are announced by BOTAS who is trying to build up new storage facilities in feasible locations. Lastly, the storage facility is also covered with the law 'The Natural Gas Market Law no: 4646' issued by Turkish Parliement in 2001.

1.1 Literature Review

Existing studies of natural gas storage are usually based on the opportunities provided by underground natural gas storage and there are many research papers that study the relationship between gas storage and prices. For instance, Höffler and Kübler studied the European natural gas market in their article. They mention that the flexibility from their own production in Europe has made gas storage less important at the moment, but their consumption increase in the course of time and their energy and heating needs will change. Therefore, the main emphasis on underground storage is about future supply of gas flexibility and high-energy consumption. (2007) Supply flexibility is especially important for regions or countries with high import dependency. (Assoumou,Maizi,2011) Supply flexibility is also crucial for sustainable growth for many countries such as China, India, and Indonesia; in addition, these countries are still working to increase their supply due to their increasing energy consumption. (Banks, 2003)

On the other hand, another important point is interaction between demand and flexibility. Shifts in demand can be countered via three alternatives. First, gas production flexibility may be a solution to meet demand swings, especially seasonal swing demand, by producing less in summer than in the winter. Second, import contracts may be unconstrained, so importing countries have a chance to balance their gas consumption. Third, one could be storing the gas for future needs. (Höffler, Kübler, 2007) For the first solution, especially for the European countries, the residential sector's demand of natural gas continues, but flexibility in domestic production is declining. (Joode, 2009) On the other hand, choosing the right production level of natural gas is the most costly alternative among the three due to the fixed and sunk costs of exploration and installation of gas production facilities. Second solution is also not realistic, because many agreements about gas imports between countries involve constant gas flows through production to importing country per year. Then, seasonal storage facilities remain as the best option. According to CIEP (2006) insufficient seasonal storage may be an important reason for shortage of gas, high price volatility and security of supply risks. Having sufficient seasonal storage facilities is the crucial tool for offsetting the increasing European demand for seasonal gas flexibility. (Rumbauskaite, 2011) Moreover, storage capability would help to improve capital potential of large supply projects, and to capture short-term supplies. (CIEP, 2006) In another article, Joode and Özdemir emphasized that seasonal gas storage can also be a solution for a problem of different types of uncertainties. These uncertainties include the overall demand for gas and the availability and competitive position of different sources of seasonal flexibility. (Joode, Özdemir, 2010) For instance, one of the important uncertainties exists due to the changes in weather conditions. Levary and Dean (1980) discuss in their papers weather conditions, which increase the demand for natural gas and necessitates coordination of supply with variable daily requirements by storing gas.

There are a few papers focusing on the relationship between storage and price fluctuations. Several factors may influence the storage level through the demand and supply changes. For instance, when a negative demand shock or positive supply shock occurs, the injection of gas stock to the market increases and the spot price declines. (Dincerler et al, 2005) Furthermore, quantity changes in the stock level over time are also necessary to model the behavior of the natural gas prices. Small quantity changes of natural gas storage can result in mean prices shifts or variability around the mean. (Linn, Zhu, 2003) On the other hand, some physical changes, such as transportation infrastructure, should be important factors for reducing excessive price fluctuations. (Chanton et al, 2008) Alternatively, the changes in information about the amount of commodity under storage also can create variability in the price of that commodity. (Linn, Zhu, 2003) Gay et al (2008) added as key determinant of natural gas prices the gas level in storage and show that markets generate different mechanism to simplify the flow of information concerning the supply of gas in storage. There is an example for this situation; the daily data from April 2002 through March 2006 for natural gas flows into and out of storage inside of California consented an examination of the approach of the future prices in the North American natural gas market. (Uria, Williams, 2007) Their study also emphasized that the combination of inter-temporal basis makes a price signal to influence storage decisions in California. In addition to that inference, net injection volumes, meaning the difference between injection and withdrawal, at the storage reservoir is considerably determined by strong seasonal cycles (Uria, Williams, 2007) These seasonal cycles can occur in different ways, which are divided as manageable, such industrial consumption, and unmanageable, such as weather. At this point, seasonal storage facilities have been used as a solution to balance these cycles more than fifty years. After 1930s, technological developments have allowed companies to invest in highly seasonal facilities. (Chanton et al, 2008) Remarkably, in the theoretical literature, there are not many articles to present the specific issue of seasonal storage. Generally in the seasonal storage literature, rational methods are used by the authors to characterize speculative storage and to estimate prices when both demand and production are random. (Chanton et al, 2008) Furthermore, storage in summer and withdrawal in winter are affected from random shocks and the limitation of natural gas. Therefore, modeling seasonal storage of natural gas is dynamic and complex. For instance, Chanton et al (2008) performed a seasonal gas market model, which is flexible and affected by the alternative policies.

2. MODEL

Storage of a commodity was studied using different models in the literature. Main studies about storage include Working (1948), Brennan (1958), Telser (1958), and Williams (1986) who explain the relationship between future and spot market prices. (Ateş, Wang, 2007) The common point of these articles is that the marginal cost of storage and the time-dependent price change are the basic components of determining the amount of a commodity held in storage. (Brennan, 1958) Further, the theory of storage presented an inverse relationship between the level of inventory and the benefit of holding this inventory. Similarly, more recent studies are also based on these components and they add that storage transfers of a commodity from one period to the next, including the related costs due to inter-temporal arbitrage. (Neumann, Zachmann, 2009)

Cho and McDougall (1990), Schwarz and Szakmary (1994), Ng and Pirrong (1996), Susmel and Thompson (1997) use the theory of storage for energy commodities in their models. Cho and McDougall (1990) analyze price variation depending on the level of inventory in crude oil, gasoline, and heating oil market. Schwarz and Szakmary (1994) investigate role of price difference in the future markets for crude oil, heating oil, and unleaded gasoline. Ng and Pirrong (1996) examine the New York heating oil and Gulf gasoline markets volatility. (Ateş, Wang, 2007)

In particular, in the natural gas storage literature, Susmel and Thompson mention that one of the benefits natural gas storage is that it provides capital gains through forward prices, so that natural gas is acceptable to be a convenience asset. (Susmel, Thompson, 1997) In the same article, another benefit is reducing the effects of supply or demand shocks, which are the results of major changes in the market structure. (Susmel, Thompson, 1997) Consequently, their model analyzes the relationship between these different benefits and find the optimal level of inventory that has a critical role in diminishing price volatility when structural change happens. Another important opportunity of storage is that inventories are a flexible source of supply in the gas sector, which increases supply elasticity. Especially, the flexibility provided by storage is seen in the seasonal storage structure, which is capable of adapting to supply and demand shocks, such as unexpected weather shocks.

Price variations depend on the stock levels with which stock prices seem to have an inverse relationship. For instance, when the inventory level is high, the spot price will be low and the inventory will pressure spot price variations. On the contrary when the spot price is high and the inventory level is around zero, the spot price volatility will increase; because the inventory level cannot decline below zero. (Modjtahedi, Movassagh, 2005) Thus, models for prediction of price volatility should be considered simultaneously with the inventory level to arrive at more accurate estimations.

Storage models build on the idea that stock value, as reflected in future prices, rises sufficiently over a period so as to cover storage costs. By the same logic, the main parameter for determining the level of commodity held in storage is the marginal cost of storage. (Uria, Williams, 2007) Depending on these propositions, future prices have been considered as the dependent variable with inventory levels. Inventory level is also important to absorb the shocks (adjust) from the change in demand and affects the convenience yield, which has an important role in the theory of storage. The benefit of convenience helps to determine forward prices depending on the storage and opportunity cost of holding inventory. All the explanations consequently lead us to investigate the relationship between future prices and stored quantities in a model where the other factors are negligible.

Specifying the Supply for Natural Gas

The supply part of commodity held in storage includes production and imports values of this commodity. Different articles in the literature also show that these variables express the supply part of the natural gas. (Bopp, 2000) The production and import levels of natural gas can change due to various effects in the natural gas market. For technical and economic reasons, production systems should be in a stable working regime to maximize usage and reduce expenditures. Accordingly, small changes in production will not affect prices too much. Nevertheless the impact here can be considered as a production cost. The total production cost of natural gas depends on different parameters, such as finding, operating and maintenance costs. Finding cost is defined that the average cost of exploration and development activities and the purchase of properties that might contain reserves. All costs incurred in finding any particular proved reserves are included in finding costs. These costs are measured for oil and natural gas on a combined basis in dollars per (barrelas of oil equivalent, boe). Another parameter is lifting cost, which is the cost of operating and maintaining wells and related equipment and facilities per barrel of oil equivalent of gas produced in facilities after the development stage. In addition, there is one more definition about the lifting cost, the direct lifting costs. It is equal to total production spending minus production taxes divided by natural gas production (measured in boe). Thus, the total lifting costs are the sum of direct lifting costs and production taxes. Then, the total production cost of natural gas is the sum of finding cost and lifting cost, and it is called upstream cost. Second cost that impacts supply is import cost, which has a critical role in low production regions. Import prices are especially significant to countries that depend on imported natural gas. There are some variables that affect import prices of natural gas. One of the important variables is transportation cost. The other important variables are tariffs and regulations, which are associated with politics, so these are more complex relationship with supply of natural gas. Another issue about the natural gas supply is its relation with crude oil. Brown and Yücel (2008) studied this topic and claimed that another impact of natural gas supply is movements in crude oil prices. They added that natural gas and petroleum products are substitutes. Furthermore, this relationship varies on some additional factors, such as weather or seasonality. Krichene also mention in another study that an expansion in the world supply of crude oil would likely be accompanied by a significant expansion in the supply of natural gas. (2002) The relationship between crude oil and natural gas is especially important for industrial use of the feedstock. If the natural gas price is lower than the crude oil prices relative to their long-term relationship, industry consumes more natural gas and this will contribute pressure to the natural gas price.

Specifying the Demand for Natural Gas

Demand for natural gas depends on some variables, which affect the consumption decision and consumption levels. These variables fluctuate gas consumption used for different purposes and so that the consumption level will change within any period, and that change brings the uncertainty for the demand parameters in the natural gas market. Different studies mention that gas demand can be considered within two periods. In the short run, gas demand can be determined by factors such as seasonality, switching between different fuels and weather. In the long run, demand depends on a number of factors, including economic growth, prices, technology, and environmental constraints on energy use. (Priddle, 1998) In this thesis, long run will be considered for indicating the gas demand. The main variable of natural gas demand is natural gas prices. There is an inverse relationship between the quantity demanded of natural gas and natural gas prices. The important point to bear in mind is the response time against the price change. The second variable that affects gas demand is GDP (income). The demand of natural gas has a strong correlation with the country's total income. High energy usage is a key indicator of GDP. In recent years, the majority of energy use in industry involves more natural gas consumption than before due to the prices and environmental reasons. A high GDP also means high personal consumption in the households. (Ghouri,2004) Both of these show that GDP is an important determinant of the demand side of the model. (Ghouri, 2004) The last variable is a trend, which captures the impact of technological changes through time. With improvements in energy efficiency, consumers will use less natural gas and still produce the same goods and services. Natural gas storage is one of the solutions to reduce uncertainty, because efficient and reliable natural gas storage is vital for managing these fluctuations in gas demand. (Thompson, et al, 2009)

While demand fluctautes, production of natural gas is relatively stable. As a consequence, during any period production and consumption level may be in a disequilibrium state, so there will be carrying over of some quantity of natural gas from that period into the next. So, in the theory of storage, balancing equation is;

$$Q^d = Q^s + \Delta I_t \quad \textbf{(2.1)}$$

$$\Delta I_t = I_t - I_{t-1} \quad \textbf{(2.2)}$$

ΔI_t refers the difference between the current and last period storage levels.

The theory of storage provide the factors that affect the level of storage. Different studies show that the inventory level has a positive relationship with storage cost. (Modjtahedi, Movassagh, 2005) Furthermore, in a competitive market, cost of storage is an important parameter to estimate future prices of the commodities. (Bopp, 2000) The cost of underground gas storage is especially influenced by the type of storage facilities and they are related to activities such as gas injection and withdrawal and performance of compressor facilities. (Thompson, et al, 2009)] Firstly, the geological and technical specifications of underground gas storage types indicate the investment cost. Secondly, the performance of withdrawal and injection is significant because gas storage is billed both on the injection and withdrawal rate of changing the storage level. (Bopp, 2000) On the other hand, cushion gas is another vital expenditure, which is needed to maintain adequate reservoir pressure and deliverability rates. Basically, then, the main result in the theory of storage is that the storage cost will be increasing in storage level at time t (Modjtahedi, Movassagh, 2005)

Convenience yield also has a significant relation with the inventory level. Since the first studies, the relation between convenience yield and inventory is one of the basic concepts of storage theory. Basically, these studies investigate the marginal convenience yield for different commodity types. Convenience yield, which plays an important role in the theory of storage, depends on several factors apart from the inventory level. Pindyck argued that the spot price, the price volatility, and the storage level affect the convenience yield. (2001) Firstly, supply and demand are very sensitive to changes in the spot price. If there is a high spot price, the shortages of supply will increase, therefore the demand for storage has a tendency to increase. According to these changes, the value of storage will increase. The last variation about the value also affects the convenience yield. Thus, the convenience yield is (in)directly changed by the spot price. Secondly, price volatility affects fluctuations in production and consumption through the changes in demand for storage. If the market volatility is higher, the demand for storage increases due to need more gas to control fluctuation for an unexpected shock. The last one is the level of inventory, which also important to determine the convenience yield. (Wei, Zhu, 2005) The marginal convenience yield value has opposite relation with the level of inventory and the current inventory level is important to determine the variation of marginal convenience value. For instance, an additional unit of inventory leads to a larger reduction in marginal convenience value if the current level inventory is low. Vice versa, if the inventory level is high, a large change in stocks is correlated with a small change in the marginal convenience yield. (Susmel, Thompson, 1997).

Hence convenience yield can be modeled as

$$C = f(P_s, P_v, G_s) \quad \textbf{(2.3)}$$

P_s , P_v , G_s refer the price shock, price volatility, and gas storage shock.

In the article of 'The supply of storage', the storage theory is investigated through different assumptions of firm behavior. (Brennan, 1958) One of the assumptions is that the firms seek to maximize net revenue in a competitive market. According to this assumption, the net marginal cost of storage per unit of time will equal to the expected change in price per unit of time. However, Brennan added that the net marginal cost of storage need not be positive and he defined the net marginal cost of storage as the marginal outlay on physical storage plus a marginal risk aversion factor minus the net marginal convenience yield.

Therefore, net marginal storage cost equals;

$$W_t - C_t = f(\Delta I_t) \quad \textbf{(2.4)}$$

where W is the marginal storage cost and C is marginal convenience yield.

From the above discussion, one sees that another component of storage demand is the risk aversion factor, or some studies present it as risk premium, which is affected by the quantity of stocks. If there is a small quantity of stocks held, there is also small risk made in investment. For instance, an unexpected shock in the price or demand, such price or demand sharply decline, at which stocks must be sold at short notice will result in a small loss to the owner of the stocks. There is also some critical level of stocks at which loss would threaten the investment and then risk will become the most important part of storage cost. (Brennan, 1958) Apart from the amount of storage, risk premium of natural gas also determines prices according to the theory of storage. (Modjtahedi, Movassagh, 2005) For instance, in the financial literature, the general view suggests that risk premium may be time-variant, and presents that the return on a broad market portfolio is one of the factors that may affect. (Deaves, Krinsky, 1992) On the other hand, the use of risk premium in the storage theory is not as complicated as financial usage. Basically, risk premium relates future prices to predicted future spot prices. The expected future spot prices is equal to future price, which is determined at the current time for delivery at future, plus a potential risk premium. (Deaves, Krinsky, 1992) According to this equation, another main factor that affects risk premium is the current prices in order to estimate the future prices and future contracts. Different studies show that risk premium can be positive or negative for natural gas market. The hedgers' and speculators' behaviours are important to indicate these risk premium signs. In energy markets, hedgers may sell futures contracts in order to insulate themselves from price fluctuations. If the speculators who are buying these future contracts can supply price insurance, which implies being rewarded by future price increases, the risk premium will be positive. Otherwise, risk premium may be negative, if the price of future contract is trading above the expected spot price between hedgers and speculators. (Deaves, Krinsky, 1992) The prediction of risk premium is not only important for these hedging and trading purposes, it is also important for taking decisions of production, storage, or consumption. In this thesis, the risk premium is also used as a predictor for future values of the spot prices in respect to the storage theory.

$$RP_t = f(F_t, P_t) \qquad \textbf{(2.5)}$$

F_t is future contract price, and P_t is spot price.

Many other studies which examine the relationship between interest rates and prices are based on and justified by the theory of storage approach. (Kitchen, Rausser, 1988) Frankel state that high interest rates reduce the demand for storable commodities through variety channels. For the natural gas market, this can be seen as two important ways. One of them is that companies may prefer extraction today rather than tomorrow due to increase in today's incentives. Another one is that firms' desire to carry inventories may decrease. (Frankel, 2006) Moreover, the amount of change in the nominal interest rate plays a role in adjusting the commodity basis. Any stored commodity, such as natural gas, should depend on the interest rate in a chosen period, because it provides to control for variation in the marginal storage cost and the marginal convenience yield in the same period. (Modjtahedi, Movassagh, 2005)

In the theory of storage, the demand for consumption is the main factor to determine the demand for storage of commodity. Another assumption related to this case is that the consumption, during any period, depends on the price in that period and the other are exogenous. Utilizing the demand, supply, and storage framework above, the equilibrium spread between a futures and a spot prices is equal to: (Fama, French, 1988)

$$F_{t,T} - P_t = R_{t,T} + RP_{t,T} + W_{t,T} - C_{t,T} \quad \textbf{(2.6)}$$

where $F_{t,T}$ is the future price for natural gas in period T , P_t is the spot price in period t, R_t is the T^{th} period nominal interest rate in period t and RP_t is the T^{th} period risk premium in period t.

2.1 Data

The US natural gas market is chosen for our model for several reasons. Firstly, the US is still the largest consumer (approximately a quarter of the total world consumption, as shown in Figure 2.1) and importer of natural gas in the world. (EIA, 2010)

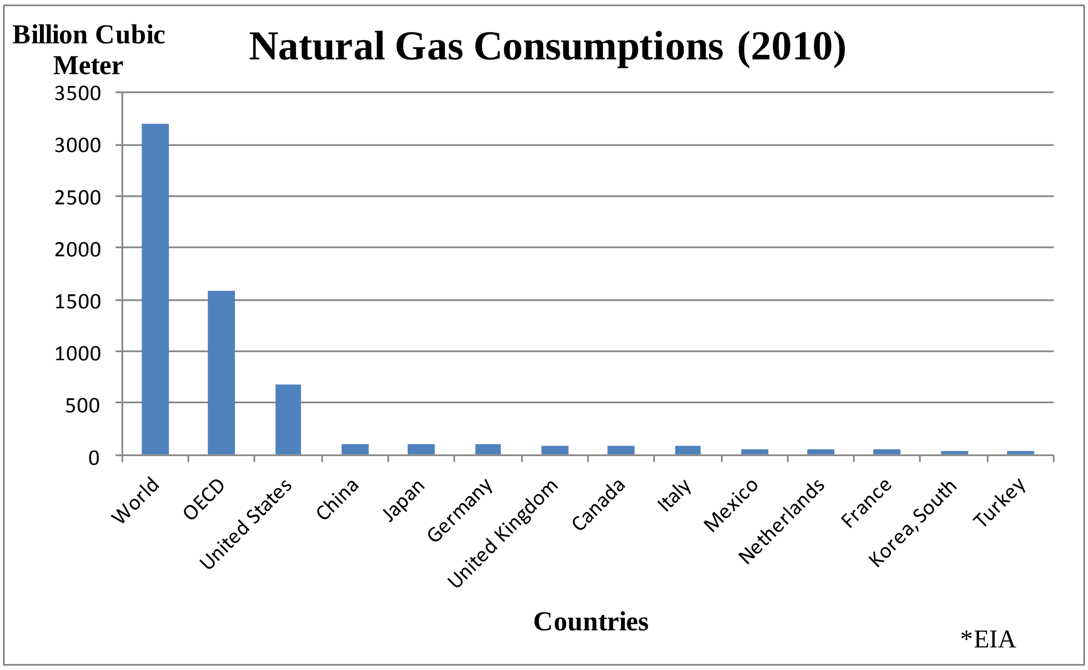

Figure 2.1: Natural Gas Consumptions for Some Countries (EIA)

Secondly, the development of storage in the US has a long history, and it involves high rate of world's storage capacity. Figure 2.2 also presents that its storage capacity is tendency to increase in the future, as well. Another important point about the US natural gas storage is shown in Figure 2.3 that the US is a unique country that involves all different storage types inside its borders. This situation can only be possible if the country has compatible geological structures with different underground storage types.

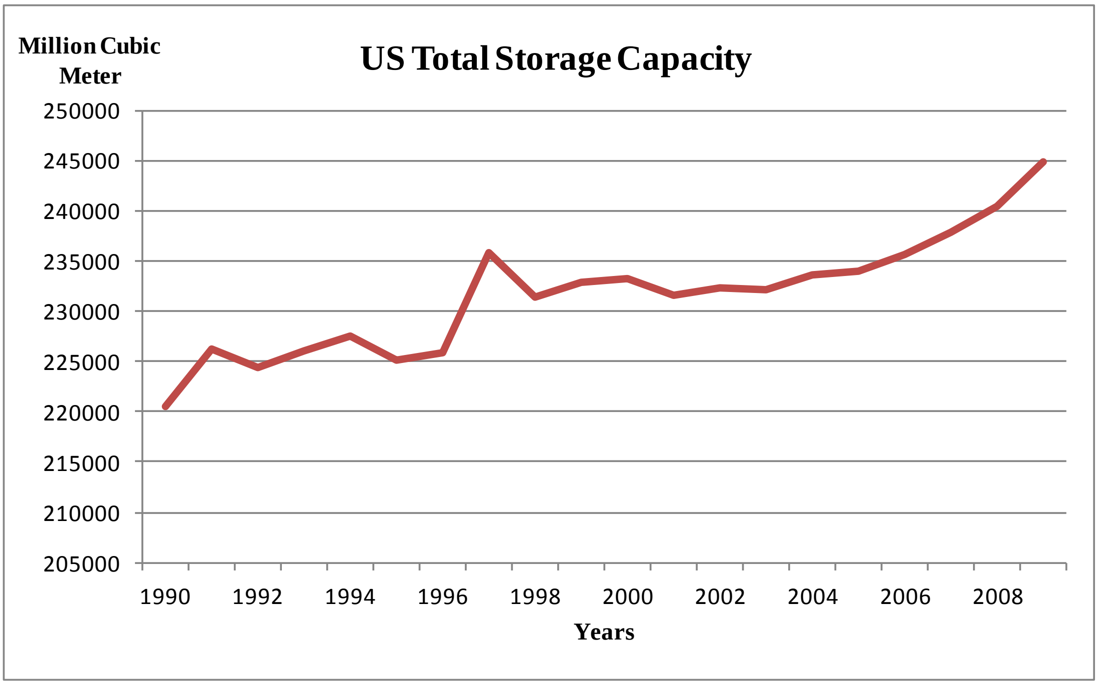

Figure 2.2: US Total Storage Capacity changes over the years in US (EIA)

The number of depleted reservoirs are significantly bigger than the other type of storage types. The main reasons for these differences are based on the investment cost and geological opportunities.

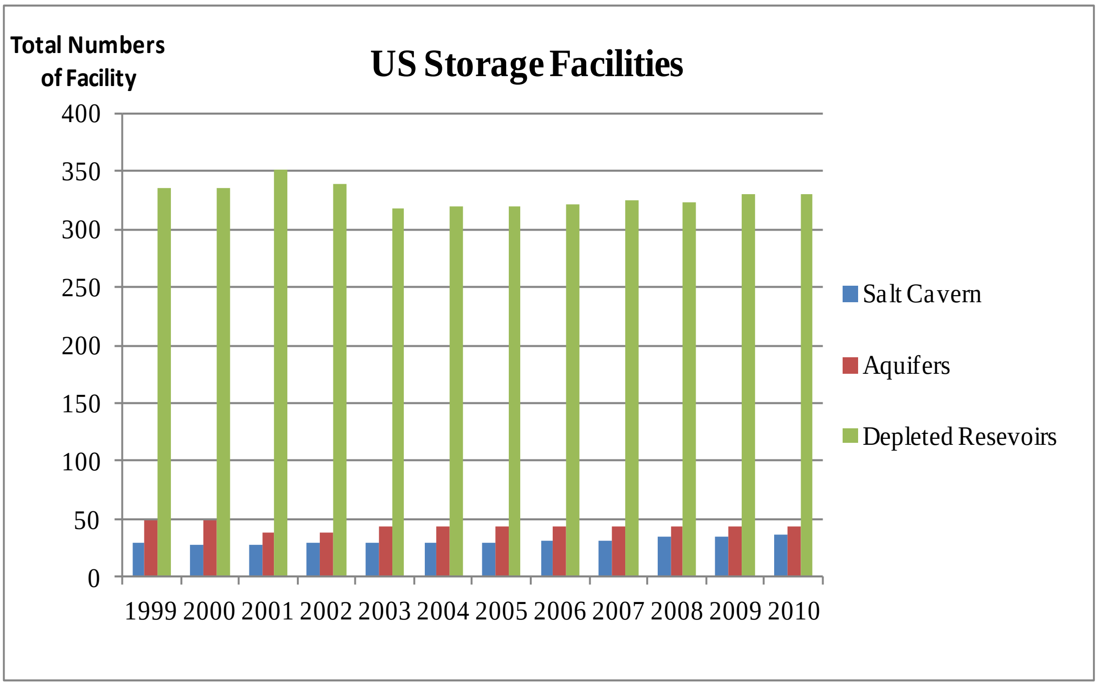

Figure 2.3: US Storage Facilities change over years (EIA)

In addition, measuring the natural gas storage is easy in the US natural gas market. Industry and government collaborate to collect extensive data on storage activities. (Susmel, Thompson, 1997) Data are collected from companies, who operate underground natural gas storage fields in United States, and also the companies must provide information, which is required because survey form (EIA-912) includes a warning, 'it is a federal crime to make any false, fictitious and fraudulent statement'. (Gay et al, 2008) The positive part of this legislation is to provide different kinds of storage data from the US natural gas market. One of these data is about storage capacity, which defines maximum operating capacity. (EIA, 2012) The storage capacity involves all type of storage in one state, such as depleted gas, salt cavern, and aquifers. According to that, Figure 2.4 presents all type underground storage capacities for different states.

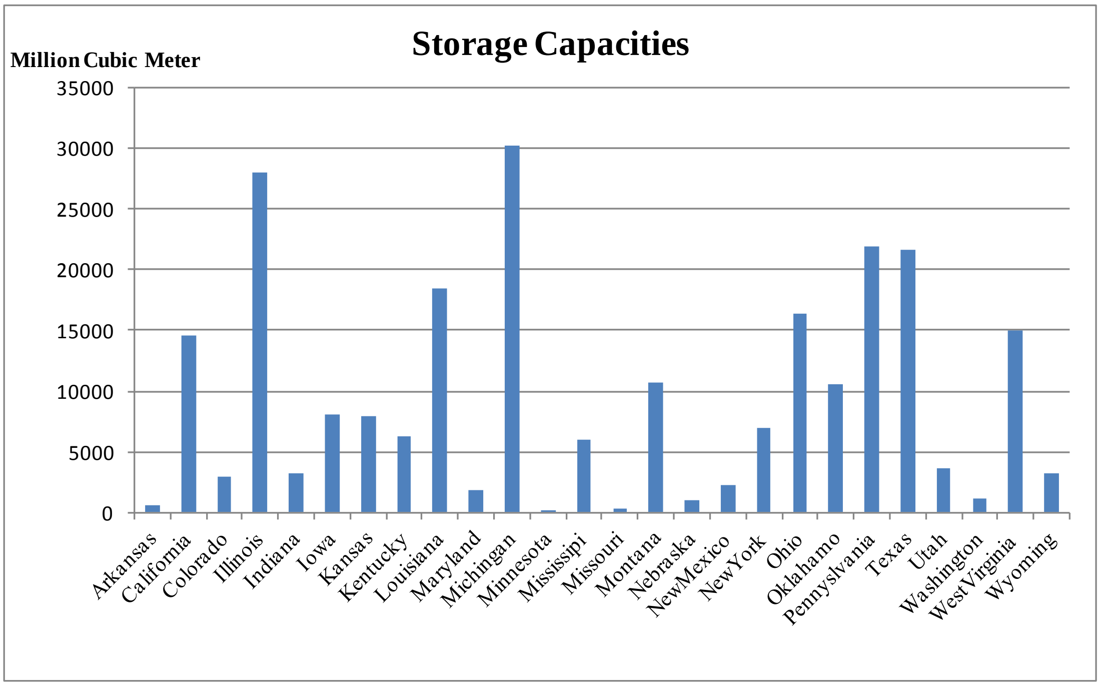

Figure 2.4: States' Storage Capacities

Under normal conditions, the total of injection and withdrawal is not equal to this maximum operating capacity. The reason is underground storage types need specified levels of gas to maintain adequate reservoir pressure. The volume of cushion gas change depeding on the storage field types, so using total gas storage data may give better results about the effects of storage volume.

The annual data for gas storage are obtained from the Energy Information Administration (EIA) of the U.S Department of Energy.

Two different price sources are needed to estimate convenience yield and future price models. The spot price data, which is used for convenience yield estimation, are obtained from the Henry Hub index provided by SNL Financial. The Henry Hub is the largest centralized point for natural gas trading in the United States. It interconnects nine interstate and four intrastate pipelines. (Buzdik, 2001) Due to these advantages, it is accepted as being a benchmark for other hub prices. (Li, 2007) Moreover, the Henry Hub index is also used for natural gas future contracts in New York Merchantile Exchange (NYMEX), which is the most liquid commodities market in the world. Figure 2.5 shows the changes in the Henry Hub spot price between 1990 to 2009. Another source of price data is used for future price estimation, and it is called the "citygate price," which is defined as a point at which distributing gas utility receives gas from a pipeline. (EIA, 2012) These data are perodically (monthly/annually) reported by U.S Energy Information Administration. (EIA, 2012)

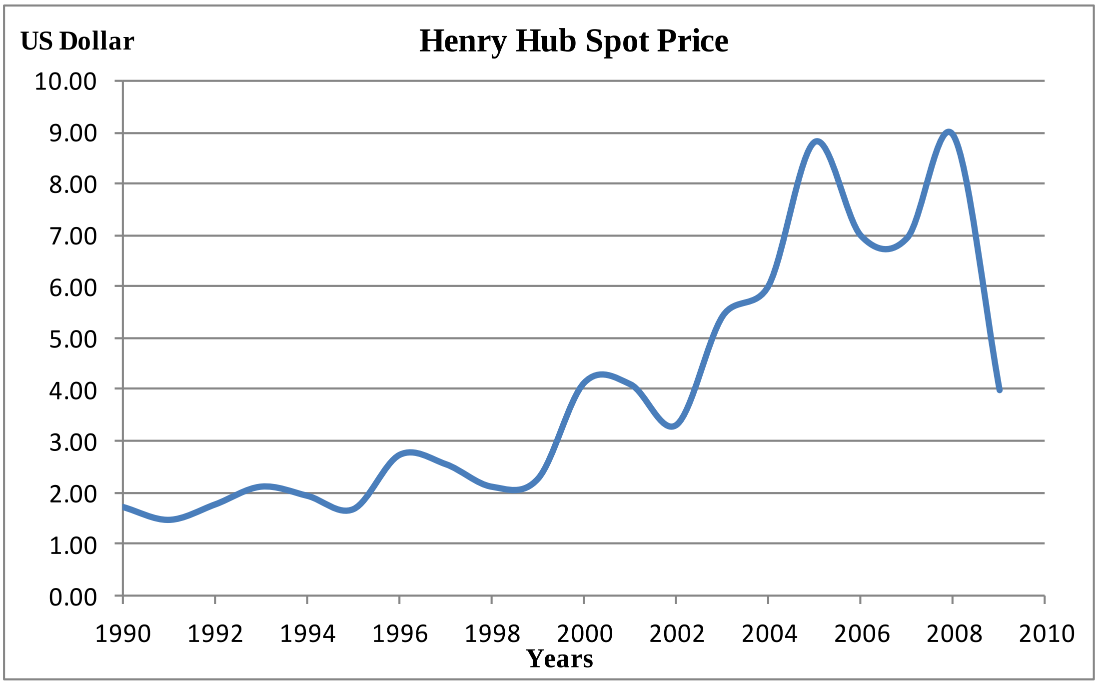

Figure 2.5: Henry Hub Spot Price for Gulf Coast ($/MMBtu)

The inflation expectation component of nominal interest rates are related with the commodity price spreads. (Kitchen, Rausser, 1988) Therefore, the future price estimation in our model uses nominal interest rate data, and these data are from the World Bank Data Indicator.

The marginal storage cost is an important parameter for the decision of holding an inventory. Although, there are many data sources on the value of marginal storage cost, they are discrete lack of continuous data series lead us to estimate a series from discrete data. These data are obtained from different sources, such as the Federal Energy Regulation Report. In general the storage cost change according to the underground storage types, but high percent of storage is depleted resevoir in US, so that the marginal storage cost for depleted reservoir is chosen for the model estimation.

2.2 Methodology

Equation 2.6 is the model specification that is estimated. In the literature, the variable convenience yield in Equation 2.6 is modeled as dependant on three factors. These are spot price, price volatility, and inventory level, and they are the proxies we use for convenience yield. According to Wei and Zhu (2006), these factors of convenience yield can be estimated from prices using the Autoregressive and Moving Average process. This process is also called as ARMA(p,q), the mixture of AR and MA schemes. ARMA is a class of linear time series model, which is widely applicable in parameterization. In general, the model is fitted by least squares regression to find values of the parameters, which minimize the error term. This method is not constructing single-equation or simultaneous equation model, it analyzes the probabilistic, or stochastic, properties of economic time series on their own under specifications. (Gujarati, 2004) Therefore, ARMA models can be considered good practice to find the smallest value of p and q that provide an acceptable fit to the data.

In this thesis, the spot price shock modeled as a residual from an ARMA(1,1) model of spot prices, the spot price volatility as the residual from the ARMA(1,1) model of price volatility which is modeled as $\sqrt{\pi/2}|P_t - P_{t-1}|$. In addition to spot price and spot price volatility, the gas storage level is modeled as the residual from an ARMA(1,1) model of the storage difference from the five-year averages. (Wei, Zhu, 2006) Hence convenience yield is specified as:

$$C = \alpha_0 + \alpha_1 P_s + \alpha_2 P_v + \alpha_3 G_s + \varepsilon \qquad \textbf{(2.7)}$$

Another variable in Equation 2.6 is the risk premium that should be determined for the main model estimation. There are various analyses to calculate the value of risk premium in the storage literature. However, two methods are usually preferred in determination of this value. One of the methods is direct estimation of the risk premium model with different parameters. Different studies use several indicators to predict the risk premium. Another approach to determination of risk premium is to obtain it from the risk premium theory. (Deaves, Krinsky, 1992) Risk premium theory relates future prices to anticipated future spot prices. The theory states that future prices at the current time for delivery in the future plus potentially a risk premium are equal to market expectations at the current time of spot price for future. (Deaves, Krinsky, 1992) Basically, this sum is defined as

$$F_t + RP_t = E_t P_{t+1} \qquad \textbf{(2.8)}$$

where F_t is future price, R_t is risk premium and E_tP_{t+1} is expected spot price for future. In the basic equation, E_t and R_t are unobservable variables, so it is not possible to calculate risk premium directly. (Kremser, Rammerstorfer, 2010) For these unknown variables, the state-space model is generally used to estimate the risk premium in respect to the theory of storage. State space models help transform the data to eliminate the dependence on the unspecified conditions, and to predict future observations, while starting it with uncertain initial conditions. (Ansley, Kohn, 1985) Especially, this approach is useful for estimates of the state vectors and predictors for missing observations.

In risk premium determination, state space model contains two equations. One of them is called measurement equation (some studies call it the observation equation), which describes the relation between observed and unobserved time series. For our prediction, observed components are spot price and future price, unobserved component is risk premium. Another equation is called transition equation and it shows the evolution of state variables. (Pichler, 2007) According to Wei and Zhu (2005), the risk premium for natural gas market can be assumed an AR(1) process.

$$P_{t+1} = \beta_1 F_t + \beta_2 RP_t + \omega \qquad \textbf{(2.9)}$$

$$RP_t = \gamma_1 RP_{t-1} + \delta \qquad \textbf{(2.10)}$$

Before starting to regression, variables should be checked for some econometric tests. First, according to the Modjtahedi and Movassagh (2005), the natural gas spot and future prices are non-stationary stochastic process, so tests for unit roots or stationarity need to be implement to the variables, especially to the prices. Stationarity has an important place in most empirical work based on time series data. It is crucial to use the sample data for forecasting due to the features of forecast models are constant through time, and especially over future periods. Therefore, stationary data are required for providing valid basis for forecasting. (Gujarati, 2004)

Autocorrelation is another remarkable point to take into account. Autocorrelation can be defined as correlation between members of series observations ordered in time for this estimation. (Gujarati, 2004) In general, time series data is likely to display autocorrelation, which should be accounted for in estimations via various correction methods.

As a result, the main model specification becomes

$$P_{t+1} - P_t = \rho_0 + \rho_1 R_t + \rho_2 RP_t + \rho_3 W_t + \rho_4 Ps_t + \rho_5 Pv_t + \rho_6 Gs_t + \varphi \quad \textbf{(2.11)}$$

Note that we have times series data for a number of states, so our data becomes panel data. Two different techniques are used and tested in the estimation of panel data. The first one is the fixed effects technique, which is generally used to control for characteristics of the individual states in our model. The fixed effects model is successful to make comparisons within states, and then averaging those differences across all the variables in the sample. The effect of the time-invariant characteristics from the estimator variables is removed by the fixed effect technique, so the technique can help to figure out estimators' net effect. (Torres-Reyna, 2009)

On the other hand, when the dummy variables represent lack of knowledge about the model, the random effects technique can be useful for estimates of panel data regressions. (Allison, 2005) Mostly, the method of generalized least squares is appropriate to estimate using the random effects technique. The number of time series data and the number of cross sectional units are important to decide the applicable method for the estimation. Different circumstances may dictate for the choice of fixed effects over random effects. The Hausman specification test is used to pick between the two. (Gujarati, 2004)

The Hausman test looks for a statistically significant difference between the two sets of coefficients. The null hypothesis for this test is that fixed effects would be consistent and random effect would be efficient, so if it is accepted the random effect method is suitable for the regression; the variables are determined efficiently; otherwise the fixed effect method is to be preferred the variables for consistency.

2.3 Analysis

In the analysis section, first, marginal convenience yield factors are analyzed. Marginal convenience yield is an important parameter for storage theory, and there are several calculation methods for predicting its value. Mostly, commodities future price theory used for the prediction, which is based on the differences of future and spot prices. To this end, the estimation method that is developed by Wei and Zhu is chosen for this aim. The estimation method consists of ARMA(1,1) model for the marginal convenience yield factors, which are spot price, spot price volatility and the storage level.

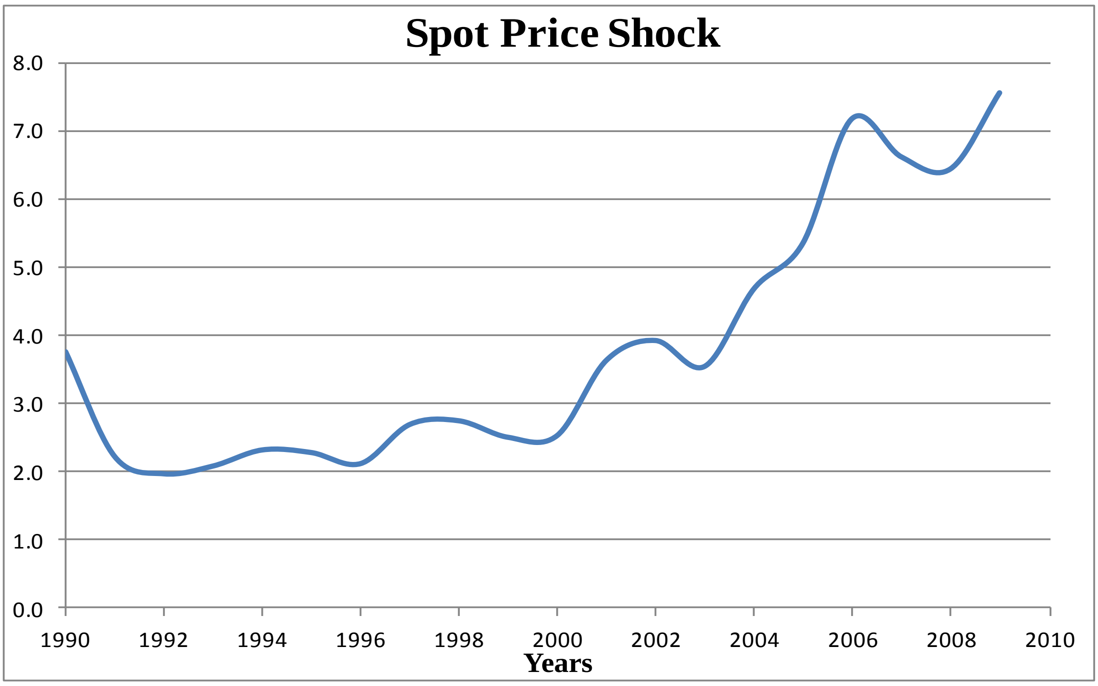

Figure 2.6: Henry Hub Spot Price Shock between the 1990 to 2009 (%)

For the sample period, the results of price shock according to the ARMA(1,1) model in the Figure 2.6 shows that the level of spot price shock becomes higher at the end of the period. There may have some different reasons, such as structural changes or financial ups and downs, to change the price shock in this period. These increases in the spot price shock are expected to significantly influence the marginal convenience yield level. Thus, the effects of this change in the marginal convenience yield will be indirectly seen in the basic model regression.

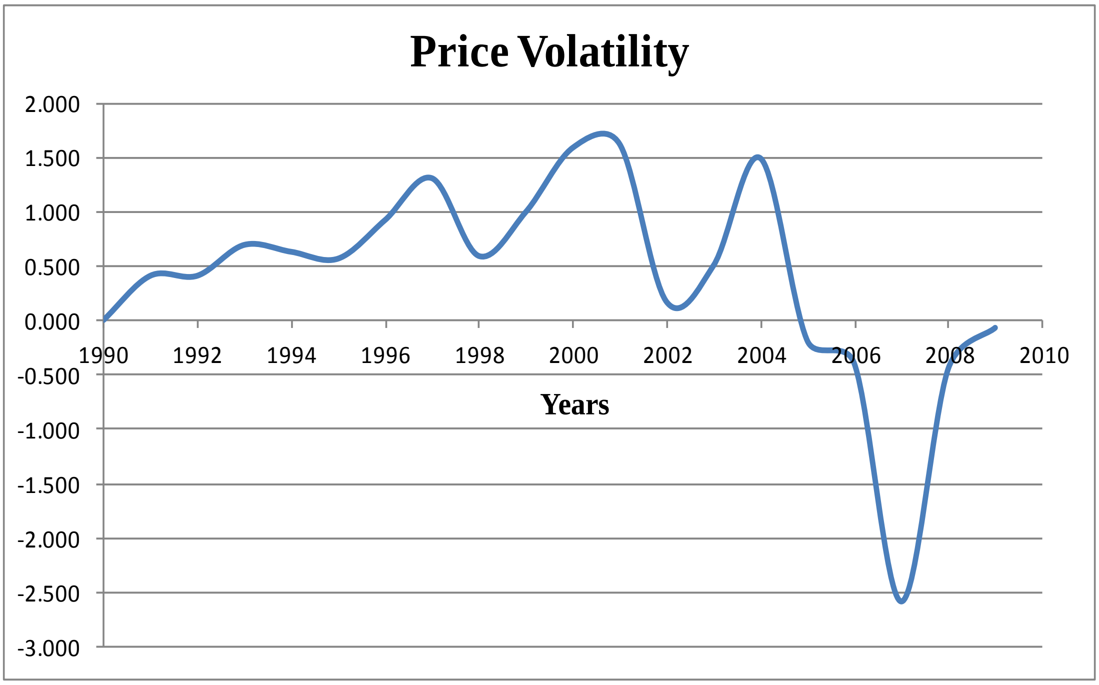

Figure 2.7: Henry Hub Spot Price Volatility between the 1990 to 2009 (%)

As expected from the spot price changes after the 2000, the spot price volatility, as seen at Figure 2.7, shows high changes at the end of period of sample. The main reason is the series of financial crises. These crises change the energy commodity prices, so the natural gas market is also affected by this uncertain environment.

Finally, gas storage shock should be determined to proxy the marginal convenience yield along with price shock and price volatility. The results of gas storage shock according to the ARMA(1,1) model indicates that the gas storage shock is significantly affected by the gas storagelevel. Especially, the states that have high gas storage capacities, show a wide range results of gas storage shock levels, because of their high injection and withdrawal level capabilities. Texas, Louisiana or Michingan are some example states of the high gas capacities (see Figure 2.8). This capability also gives a chance to be more resistant to sudden shocks from the supply and demand changes. Finally, different studies also emphasize that the inventory level of natural gas as an important parameter to explain the changes in the marginal convenience yield.

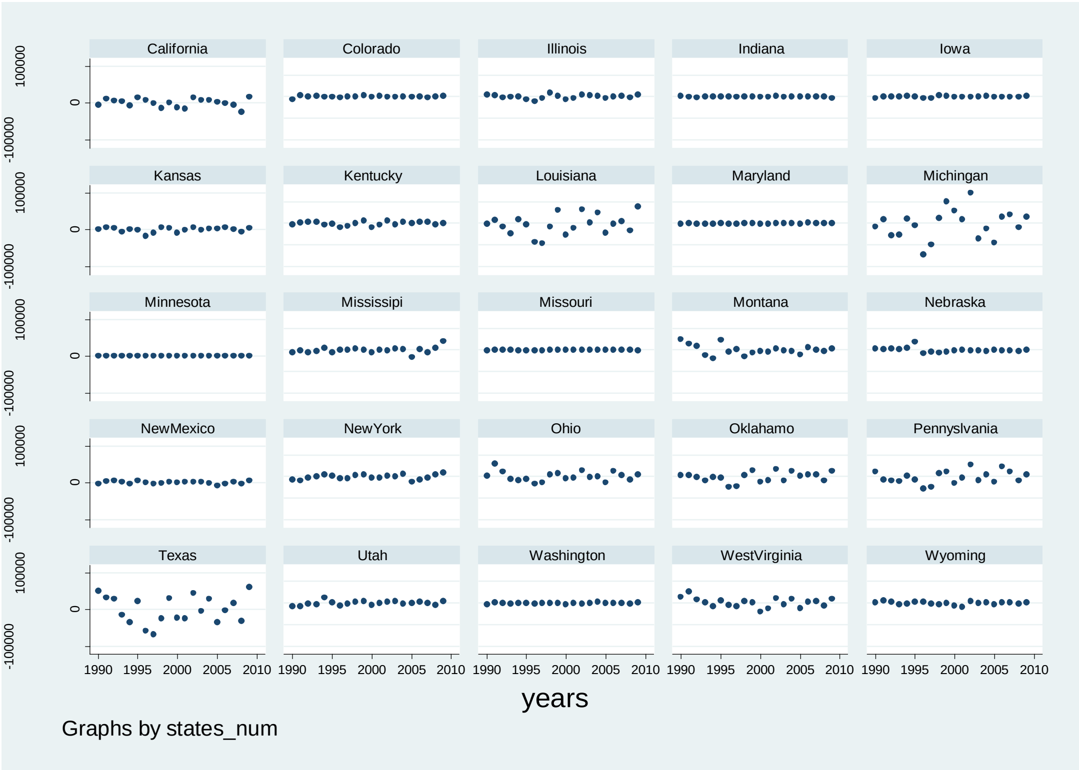

Figure 2.8: States Gas Storage Shock between 1990 to 2009

Another unobservable parameter is risk premium in the main model. For the unobservable variables, the economic literature pointed using the state space model technique. According to the different studies in the risk premium estimation, state-space models are also suitable for predicting the values of risk premium. One of the advantages of state space models is that straightforward to implement it to the complex problems. In addition to that, it also provides a simple representation about these complex problems. In this thesis, the state-space model helps to estimate risk premium for the natural gas storage, which helps explain the relation between future spot prices and spot prices. Based on this relationship, the estimation results show that the future price movements vary from 1990 to 2009.

Variable	Obs	Mean	Std. Dev.	Min	Max
rp_9099	10	.054125	.0311821	.006	.1142498
rp_0009	10	.1411825	.0536065	.0788656	.2513366
rp_9009	20	.0976537	.0617758	.006	.2513366

Table 2.1: Descriptive statistics of risk premium as a percentage of spot prices

Table 2.1 presents the descriptive statistics of the estimated risk premium for three different periods. First period is between 1990 to 1999, the second period is between 2000 to 2009, and the last one contains both of these periods. At the first period, the estimated risk premium is not so high, because there are not big changes in price level during this term. On the other hand, second period does not resemble to first one, and the estimated risk premium increases due to high variation in price level. (for details, see Figure 2.9)

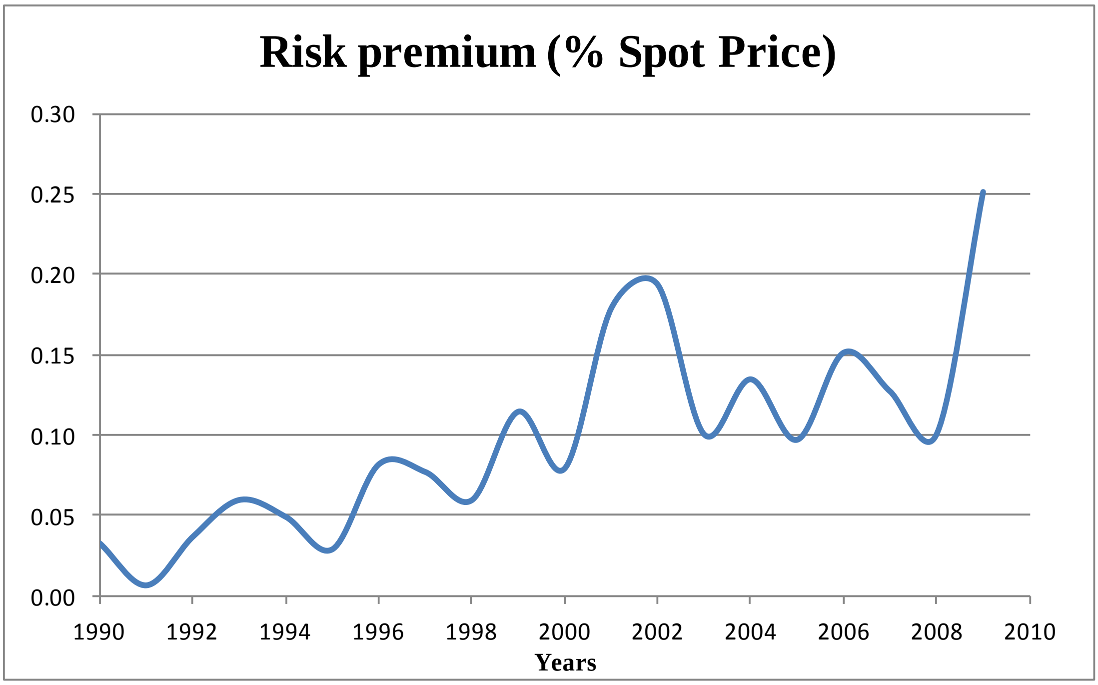

Figure 2.9: Risk Premium as a percentage of Spot Price

Considering the estimation of risk premium as a whole, risk premium has a tendency to increase throughout the time, especially at the end of the sample period. The main reason about the risk premium increase is that there are a lot of uncertainities in the natural gas market after 2000s. In particular, exogeneous external shocks affect the price level negatively, hence, the gas using from the underground storage could be more expensive than the previous period.

Before starting with the regression analysis, the unit root tests (for stationarty) should be applied to variables, but taking into account the panel structure in the data. Hence, Levin-Lin-Chu method used for the unit root test. According to this method, the same AR(1) coefficient is assumed each individual unit in the panel, but in addition to that the method allows for individual effects, time effects and possibly a time trend. (Bornhorst, Baum, 2006) As a results of these tests, the variables risk premium, citygate prices, price shock, and price volatility, which are used in the main regression, have unit roots so that the first differenced of these variables are used while regressing the main model. In the next step, the variables tested for autocorrelation. Tests indicate possibility of autocorrelation in the variable price volatility, so this finding is taken into account in estimations.

Before the estimation of main model, the coefficient signs would be expected as in Table 2.2:

Explanatory Variables	Expected Effects on the Dependant Variable	Statements
Interest forgone	Negative	High interest rates reduce the demand for storable commodities through two channels: -Companies may prefer extraction today rather than tomorrow due to the increase in today's incentives -Firms' desire to carry inventories to decrease These situations create an expectation in inverse relation between the spot prices and interest rates. [Frankel,2006]
Risk Premium	Positive/Negative	Different studies show that risk premium can be positive or negative for different natural gas market. The hedgers' and speculators' behaviours are important to indicate these risk premium signs. [Deaves, Kinky, 1992]
Marginal Storage Cost	Positive	According to the main articles of storage theory, 'The supply of storage' and 'Commodity Futures Prices: Some Evidence on Forecast Power, Premiums, and the Theory of Storage', the basis should be an increasing function of storage cost. [Brennan, 1958][Fama,French,1988]
Price Shock	Negative	According to the study of Wei and Zhu about the US Natural Gas Market, the empirical results presented that the price shock has positive relationship with the marginal convenience yield. Normally, the marginal convenience yield has inverse relation with the basis from the main storage theory, so price shock is expected negative for US Natural Gas Market. [2005]
Price Volatility	Negative	From the same empirical results (Wei and Zhu's article), price volatility is expected in inverse relation with basis.[2005]
Gas Storage Shock	Positive	From the same empirical results (Wei and Zhu's article), gas storage shock has a direct relation with basis.[2005]

Table 2.2: Expected Effects of Explanatory Variables on the Dependant Variables

The main model is estimated with two different techniques. The first one is fixed effects, and the second is random effect technique. Then, a Hausman test is conducted to determine the preferred for the model estimation. The null hypothesis of Hausman test is that the coefficients obtained from fixed and random effects are statistically the same. Since fixed effects coefficients are consistent and random effects technique is more efficient, when null hypothesis is not rejected, random effects results are to be used. From the result, it is not possible to reject null hypothesis, so random effect method can be used for the main regression. It means that the coefficients from the random effect are preferable to use for main model coefficients. (See appendix for the results of Fixed Effect and Hausman test)

According to the random effect technique results in the Table 2.3, all the explanatory variables, except price shock, are statistically significant. The result of two-tail-p-values test of the price shock residuals is greater than %10, which means that it is not possible to reject the each coefficient is different from zero. The interest forgone, which is defined as nominal interest rate multiplied by citygate prices, and risk premium are negatively correlated with basis. (Basis is defined as the difference of future and current prices in the storage literature) The result of interest forgone is acceptable for the yearly data of nominal interest rates. Previous studies presented both signs for 3 and 6 months interest rates, but their results are consistent with this estimation of 12 month interest rates. (Modjtahedi, Movassagh, 2005) In addition, the coefficient sign of interest forgone is consistent with the Frankels' study, as mentioned before in Table 2.2. Risk premium is an interesting concept in the theory of storage for US gas market. It is correlated with the spot price, and it is also calculated on future contracts traded in US. Its sign probably depends on the hedging behaviour of producers and buyers. (Deaves, Krinsky, 1992) For this reason, the coefficient of risk premium may be meaningful for the US Natural Gas Market. As it is expected, the marginal storage cost has a positive effect on the basis, and it constitutes an important part in explaning changes in differences about future and current prices. If the market volatility is higher, the demand for storage increases due to need more gas to control fluctuation for an unexpected shock. This situation affects to increase spot price level, thus the relation between basis and price volatility is inverse. Most important point is that the gas storage shock is also statistically significant, so that there is a relation between inventory level and basis. Especially, the positive sign of gas storage shock increases the value of basis. As it is mentioned before, the high gas storage shock values can occur with high storage level, therefore increasing the storage level or storage capacity give a chance to affect the price level.

```
RE GLS regression with AR(1) disturbances          Number of obs      =       450
Group variable: states_num                         Number of groups   =        25

R-sq:  within  = 0.5380                            Obs per group: min =        18
       between = 0.0762                                           avg =      18.0
       overall = 0.5276                                           max =        18

                                                   Wald chi2(7)       =    567.88
corr(u_i, Xb)      = 0 (assumed)                   Prob > chi2        =    0.0000

----------------------------------------------------------------------------------------
                  D.F_S |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
------------------------+---------------------------------------------------------------
      interest_forgone  |  -.0532241   .0054507    -9.76   0.000    -.0639074   -.0425409
   marginalstoragecost  |   9.459946   1.384288     6.83   0.000     6.746792     12.1731
                        |
                     rp |
                    D1. |  -4.513657   .2846051   -15.86   0.000    -5.071473   -3.955841
                        |
        hh1price_shock  |
                    D1. |  -.1902582   .1198847    -1.59   0.113    -.4252279    .0447114
                        |
hh1pricevolatilitylog   |
                    D1. |  -.4997308   .1074379    -4.65   0.000    -.7103052   -.2891565
                        |
       gasstorageshock  |    .000013   5.47e-06     2.37   0.018     2.27e-06    .0000237
                  _cons |  -3.104906   .6966906    -4.46   0.000    -4.470394   -1.739417
------------------------+---------------------------------------------------------------
                 rho_ar |  -.2634026   (estimated autocorrelation coefficient)
                sigma_u |          0
                sigma_e |  1.3611326
                rho_fov |          0   (fraction of variance due to u_i)
                  theta |          0
----------------------------------------------------------------------------------------
```

Table 2.3: The results of Random effect method (using software Stata)

3. SUMMARY, CONCLUSION, AND POLICY RECOMMENDATIONS

This thesis provides a complete econometric model of the difference between future and current spot prices, the "basis." Various applications of Storage Theory implies for natural gas market the usage of interest rate, risk premium, storage cost, and convenience yield as determinants of the basis.

Among these variables, convenience yield, defined by Brennan as the benefit of holding inventory, has an important role in the storage theory, and this thesis proxies it with price shocks, price volatility, and storage shocks. In addition, Brennan emphasize that the convenience yield has an inverse relationship with the level of inventory. In the following years, other studies indicate that the convenience yield is not only relative with the inventory level, but it also has relationships with price shocks and price volatility. In the convenience yield model in this thesis we derive price shocks and price volatility using the ARMA(1,1) method. First, the storage shock is defined as the difference between a year's value and the five year average around that year, and then it is derived by using ARMA(1,1) method.

Risk premium is another important term in theory of storage. Risk premium is an unobservable variable, so that we should also estimate it from other variables. The thesis uses the state space model to solve the risk premium values. State space models help to transform the data, and to predict future observations, while starting it with uncertain initial conditions. After that, the risk premium values can be used in the main model.

Finally, the main model regressed the difference between future and current spot prices on these variables using fixed and random effects techniques. Both techniques give similar results, so we used the Hausman test to determine the preferred one. Random effects technique turns out to be the preferred one.

In the preferred model, interest rate, risk premium, price shocks, and price volatility have negative and storage cost and gas storage shocks have positive coefficients as predicted by the theory. All these coefficients are statistically significant with the exception of price shock which has a p-value of 11%. Gas storage shock is modeled from the working gas capacity, which represents the volume of gas that can be delivered to end users. It is also described as total injection and withdrawal capacity for operating gas volumes. Thus, the gas storage shock level represent the changes in inventory level, and the changes in inventory level mainly depend on the storage capacity level. The high gas storage shock values can occur with high storage level, and consequently increasing the storage level or storage capacity give a chance to affect the price level, which lends the system vulnerable to speculation.

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APPENDIX

```
FE (within) regression with AR(1) disturbances  Number of obs      =       425
Group variable: states_num                      Number of groups   =        25

R-sq:  within  = 0.5719                         Obs per group: min =        17
       between = 0.1507                                        avg =      17.0
       overall = 0.5400                                        max =        17

                                                F(6,394)           =     87.73
corr(u_i, Xb)  = -0.1456                        Prob > F           =    0.0000

------------------------------------------------------------------------------------
               D.F_S |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
---------------------+--------------------------------------------------------------
    interest_forgone |  -.0541692   .0059457    -9.11   0.000    -.0658585   -.0424799
  marginalstoragecost |   9.247446   1.470479     6.29   0.000     6.35648    12.13841
                     |
                  rp |
                 D1. |  -4.135499   .3443236   -12.01   0.000    -4.81244    -3.458557
                     |
      hh1price_shock |
                 D1. |    .375957   .2964161     1.27   0.205    -.2067979     .958712
                     |
hh1pricevolatilitylog |
                 D1. |  -1.012818     .26852    -3.77   0.000    -1.54073    -.4849072
                     |
     gasstorageshock |    .0000131   5.93e-06     2.22   0.027    1.49e-06     .0000248
               _cons |  -1.724697   .5409008    -3.19   0.002    -2.78811    -.6612846
---------------------+--------------------------------------------------------------
              rho_ar |  -.2634026
             sigma_u |  .21259935
             sigma_e |  1.4035123
             rho_fov |  .02243051   (fraction of variance because of u_i)
------------------------------------------------------------------------------------
F test that all u_i=0:     F(24,394) =     0.20               Prob > F = 1.0000
```

Table A.1: The results of Fixed effects estimation (using software Stata)

	Coefficients			
	(b) fixed	(B) random	(b-B) Difference	sqrt(diag(V_b-V_B)) S.E.
interest_f~e	-.0541692	-.0532241	-.0009451	.0023751
marginalst~t	9.247446	9.459946	-.2124994	.49604
D.rp	-4.135499	-4.513657	.3781584	.1938006
D.hh1price~k	.375957	-.1902582	.5662153	.2710907
D.hh1price~g	-1.012818	-.4997308	-.5130876	.2460896
gasstorage~k	.0000131	.000013	1.50e-07	2.27e-06

```
                          b = consistent under Ho and Ha; obtained from xtregar
           B = inconsistent under Ha, efficient under Ho; obtained from xtregar

    Test:  Ho:  difference in coefficients not systematic

                  chi2(5) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                          =        6.05
                Prob>chi2 =      0.3013
```

Table A.2: The result of Hausman test (using software Stata)

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